Centre for Affordable Water and Sanitation Technology

Summary of Field and Laboratory Testing for the Biosand Filter

In this document you will find:

- ***Short summaries of field and laboratory tests for the biosand filter and the Kanchan™ Arsenic filter (biosand filter adapted for arsenic removal)***
- ***Summary tables showing:***
  - ***Biosand filter study findings and results***
  - ***Kanchan™ Arsenic filter study findings and results***

All documents are categorized and listed in the following order:
1 – Peer reviewed, published papers
2 – High quality, unpublished papers
3 – Informal reports (field study, PowerPoint presentation, press release, personal communication)
4 – Anecdotal reports/studies

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PART 1: BIOSAND FILTER FIELD AND LABORATORY STUDIES

CATEGORY 1 – PUBLISHED PAPERS

Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Access to Safe Drinking Water (2008)

Sobsey, M.D., C.E. Stauber, L.M. Casanova, J.M. Brown, and M.A. Elliott
Source: Environmental Science & Technology, Web Published May 13, 2008
Abstract Available at: http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/asap/abs/es702746n.html

Sobsey, et al. compare five different household water treatment technologies according to criteria for performance and sustainability. Technologies were included in the paper if there was existing evidence of microbiological efficiency and diarrheal reduction in published studies. The technologies included were chlorination with safe storage, combined coagulant-chlorine disinfection systems, SODIS, ceramic and biosand filters. The performance criteria included a review of the microbial removal efficiency and evidence of health impact for each technology. Sustainability was evaluated according to six different criteria: water quantity produced; treatment robustness (ability to treat a variety of source waters); ease of use and time treating water; cost to treat; and ability to sustain high use levels after the intervention and education efforts have been completed. According to these evaluation criteria, ceramic and biosand filters are the most effective household water treatment technologies. The authors conclude that these two types of filters have the greatest potential for widespread use and adoption to achieve sustained health impact.

Reductions of E. coli, echovirus type 12 and bacteriophages in a biosand filter (2008)

M.A. Elliott, C.E. Stauber, F. Koksal, F.A. DiGiano, M.D. Sobsey
Source: Water Research, Volume 42, Issues 10-11, May 2008, Pages 2662-2670
Available Abstract at: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-4RNR6VS-3&_user=10&_coverDate=05%2F31%2F2008&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=96a46a32371471c60fd9416f72ad81de

The study investigators set forth three major objectives for their research: understand hydraulic flow condition within the biosand filter, investigate the ability of the biosand filter to reduce enteric bacteria and viruses in water, and understand key operating parameters and their effects on filter performance. Filter performance depended on the ripening time (time it takes for the biolayer to develop) and volume of water poured into the filter daily. Filter performance was best when less than 18.3 L of water (one pour volume) was poured into the filter each day and after approximately 30 days of filter ripening. After 30 days of ripening time, the biosand filter reduced *E. coli* by almost 99% on average. Virus removal by the biosand filter differed greatly depending on the specific viral agent. Of the two different types of viruses tested, the biosand filter reduced echovirus 12 by more than 99% on average; however, the filter reduced bacteriophage concentrations by 70% on average. The paper identifies that the pause period for the filter is an important operating parameter and that this research has implications on the recommended quantity of water per day and frequency of use.

Effects of operating conditions on the bacterial removal of two household drinking-water filters (2007)

Jill Baumgartner, Susan Murcott, & Majid Ezzati; Harvard School of Public Health, Massachusetts Institute of Technology
Source: Environmental Research Letters, 2 (2007) IOP Publishing
Available at: http://www.iop.org/EJ/article/1748-9326/2/2/024003/erl7_2_024003.pdf?request-id=5uxprOmA3BGq5Z7K2wi7Kg

This study investigated the performance of the BSF with respect to pause times between filtration runs, water-dosing volumes and the effluent volume at which a filtered water sample was collected. Three scenarios were compared by the authors, including infrequent filtration (36 hours) and high water dosing volume (20 liters), frequent filtration (12 hours) and high water dosing volume (20 liters), and frequent filtration (12 hours) and low water dosing volume (10 liters).

The study showed:

- Total coliform removal by the BSF decreased with an increase in the sample collection volume, i.e. at 5 liters of effluent the percent removal was greatest
- Greater removal of total coliforms when filter pause period is 12 hours versus 36 hours

Key lessons learned:

- Encourage users to filter 5 L of water at a time or when filtering more than 5 L at a time, use first five liters for drinking/cooking and the remainder for other household needs

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Characterization of the BSF for Microbial Reductions- Lab and Field Conditions (2006)

Christine E. Stauber, Mark Elliott, Fatma Koksal, Gloria M. Ortiz, Kaida Liang, Francis A. DiGiano, and Mark D. Sobsey ; University of North Carolina at Chapel Hill
Source: Water Science & Technology Vol 54 No 3 pp 1–7 Q IWA Publishing 2006
Abstract Available at:
http://www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed&uid=17037125&cmd=showdetailview&indexed=google

The objective of this study was to determine the ability of the BSF to reduce concentrations of bacteria, coliphages and human enteric viruses and to changes in filter effectiveness with biological ripening and length of operation

- Ripening time varies, probably due to influent water quality
- 95-98% reduction of *E. coli* in a ripened filter
- ~80-90% virus reductions in a ripened filter
- In the field, filters near Bonao DR are reducing *E. coli* an average of about 90%

Performance of BSF in Haiti: A Field Study of 107 Households (2006)

Baker, D.L., Duke, W.F., Mazumder, A. and R. Nordin
Source: Rural and Remote Health. 6: 570. (Online), 2006.
Available at http://www.rrh.org.au/publishedarticles/article_print_570.pdf

A field study of 107 households was conducted to evaluate the use and performance of the Manz biosand filter in the Artibonite Valley of Haiti. Approximately 2000 filters had been installed in this area over the preceding five years by the staff in Community Development at Hospital Albert Schweitzer. Water analyses were performed by Haitian lab technicians using the membrane filtration method to determine *E. coli* counts.

Description	Contamination	Removal
Shallow wells (source)	243 E.coli cfu/100ml	-
Piped water (source)	195 E.coli cfu/100ml	-
Average biosand filter efficiency of bacterial removal	-	98.5%
Biosand filter Turbidity removal	6.2 NTU	0.9 NTU

The Long-term Sustainability of Household Biosand Filtration (2004)

E. Fewster, A. Mol, and C. Wiesent-Brandsma
Source: 30th WEDC International Conference, Vientiane, Lao PDR (2004)
Available at:
http://www.biosandfilter.org/biosandfilter/files/webfiles/Bio_Sand_Filter_Article_WEDC_Conference_2004.pdf

This paper was submitted to the WEDC International Conference in 2004 based on an evaluation of a project in the Machakos District of Kenya that began in 1999. 51 filters were tested for bacterial and turbidity removal after four years of operation.

The evaluation found that:

- 70.5% of filters achieved 0-10 faecal coliforms per 100 mL (The percentage of filters that achieved this level of microbial reduction four years earlier was 80.7%)
- 82.4% of filters achieved turbidity reduction of less than 10 NTU
- Outlined possible linkage between user cleaning behaviour and failure to achieve good microbial reduction – operation and maintenance information to users needs to be improved, including improved follow-up visits and increased frequency of visits.

Toxicant and Parasite Challenge of Manz Intermittent Slow Sand Filter (1999)

Palmateer, G., Manz, D., Jurkovic, A., McInnis, R., Unger, S., Kwan, K. K., Dudka, B. J.
Source: Environmental Toxicology, vol. 14, pp. 217- 225 (1999)
Abstract available at: *http://www3.interscience.wiley.com/cgi-bin/abstract/60000404/ABSTRACT?CRETRY=1&SRETRY=0*

Safe potable water is a luxury that is generally unavailable to the majority of rural and suburban populations of developing, underdeveloped, and often developed countries. Important considerations in the development and maintenance of safe water supplies is the availability and use of efficient, inexpensive, and appropriate technology for removing microbial hazards, parasites, and toxicants. The Manz intermittent slow sand filter was known to be user friendly, small enough to fit into the smallest kitchen, and could remove up to 97% of the fecal coliforms present in the raw water before treatment by the Manz filter. This filter was evaluated for its ability to remove parasitic cysts and toxicants as well as bacteria. Using two different filters and

two different water supplies our results indicated that the intermittent slow sand filter could remove 83+% total heterotrophic bacterial populations, 100% of Giardia cysts, 99.98% of Cryptosporidium oocysts, and 50-90% of organic and inorganic toxicants when administered in concentrations varying from 10-100x environmental pollution levels. Methodology details are provided in the paper.

CATEGORY 2 – HIGH QUALITY UNPUBLISHED PAPERS

Evaluation of Household Biosand Filters in Ethiopia (2006)

Paul Earwaker
Source: Cranfield University Silsoe, MSc Water Management (Community Water Supply)
Available at: https://dspace.lib.cranfield.ac.uk/handle/1826/1454

An evaluation was conducted to evaluate filters in rural Ethiopia that were installed more than 5 years previously. Filters from three villages were examined to assess filter performance, maintenance practices, user perceptions and the supporting environment. The investigation utilized a range of methods including water testing, observation and semi-structured interviews.

A brief summary of the evaluation is as follows:

- 44% to 88% of total filter are used in each village
- 87.9% reduction rate of E. coli in the working filter
- 81.2% of the filtered water have less than 5 TU.

The poor performance of some filters and low usage rates in some villages were attributed to the quality of maintenance, the lack of reinforcement of educational messages and the support provided to filter users.

Nepal Water Project – Massachusetts Institute of Technology (2001)

Tse-Luen Lee; Biosand Household Water Filter Project in Nepal
Nathaniel Paynter; Household Water Use and Treatment Practices in Rural Nepal
Source: Masters Theses, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology
Available at: http://web.mit.edu/watsan/std_thesis_nepal.htm

A total of thirty-nine sets of BSF samples were tested. Each set of samples consisted of two individual tests; one sample of water before filtration and one after filtration by the BSF for a total of seventy-eight individual tests.

Number of BSF test samples analyzed

	Turbidity	H2S	Total Coliform	E. coli
Palpa	12	12	2	2
Nawalparasi	66	66	36	36
Total	78	78	38	38

Of the thirty-nine BSFs that were evaluated in Nepal, fourteen of them did not show favourable results in terms of the removal of microbial contamination (i.e. H2S bacteria, total coliform, E. coli). Of the subset that did not work, 63% were found to have problems either with the diffuser plate, the resting water level or the maturity of the biofilm. Since these filters may not be representative of the microbial removal efficiency of the BSF, they were excluded in the results.

The results of filters that were working properly shows 75% removed total coliform, 83% removed E. coli and 89% removed H2S-producing bacteria.

Thirty-six BSFs out of forty-two visited had been used in the last week, while three others had been used in the past four months. The remaining BSFs were not in use either because of problems with the construction (two BSFs) or because the BSF was inconveniently located. 93% of the respondents overwhelmingly liked the BSF, particularly citing the treated water's taste, and the BSF's high flow rate, cooling properties, as well as turbidity removal (Paytner, 2001).

Membrane filtration tests carried out at MIT by Tse-Luen Lee indicate that the BSF technology is effective at removal of total coliform with an average removal of 99.5% of total coliform in the source water. During the test period, about 20L of water from the Charles River was collected every day (except weekends) and passed through the filter. The BSF was allowed 45 days to mature. Membrane filtration tests were then carried out.

The medium used was the m-Endo broth manufactured by Millipore, which tests for total coliform. The results of the membrane filtration tests are shown in Table 8. Average percentage removal of total coliforms is 99.5% after being in operation for 45 days. This verified that the BSF is a fairly effectives technology for the removal of total coliforms in water.

Membrane filtration total coliform results

Trial Number	Date	Influent (CFU/100mL)	Effluent (CFU/100mL)	% Removal
1	April 28	560	3	99.46
2	April 29	610	5	99.18
3	May 1	680	3	99.58
4	May 2	590	2	99.66
5	May 5	730	2	99.72
Average		630	3	99.52

Intermittently Operated Slow Sand Filtration – A New Water Treatment Process (1995)

Brian J. Buzunis
Source: Masters Thesis, Department of Civil Engineering, University of Calgary (Electronic version available through CAWST)

- Filter is effective in removing 96% of faecal coliform indicators and reducing turbidity levels to < 1 NTU
- A mathematical model to describe the diffusion of oxygen transfer into the filter bio-layer was developed and supported by experimental data.
- Considerable data was taken over a 55 day test period using influent water averaging 1300 CFU/100 ml taken from a river lagoon.

Nicaragua Household Water Supply and Testing Project Final Report (1993)

David Manz, Byron Buzunis, Carlos Morales
Available at: http://www.manzwaterinfo.ca/documents/Nicaragua%20Report%201993.pdf

- Pilot project with plastic filter -- operated well but too complex, leakage and valves were stolen
- Concrete filter developed -- Cost was $20 US
- Valle Menier
- 55 households, 326 people
- 55 filters installed in households and 1 in a school
- 15 water sources
- Each filter had 3 faecal coliform tests in June 94 and Nov 94.
- After 21 days of operations -- faecal coliform removal -- low was 86.67 % with a high of 100 % and average of 97 %
- After 2 months of operation -- faecal coliform removal -- average for 55 filters was 96.4%

CATEGORY 3 – INFORMAL REPORTS (FIELD STUDY, POWERPOINT PRESENTATION, PRESS RELEASE, PERSONAL COMMUNICATION)

UNC Independent Assessment of Biosand filter in Cambodia (2007)

Kaida Liang, Mark Sobsey, Proum Sorya, & Mickey Sampson
Source: September 2007 Presentation in Cambodia

This cross sectional study investigating BSF use was conducted between December 2006 and January 2007 among recipients of biosand filters through two NGOs- Hagar and Cambodia Global Action (CGA). 336 households were selected at random from over 21,000 households reported to have received biosand filters in the region. Households were interviewed to determine water handling practices and use, filter use and maintenance, and sanitation and hygiene practices.

The cross-sectional study showed the following:

- Filter use ranged from 0-8 years
- 87.5% of households were still using their filter
- Continued filter use was significantly associated with:
    - Reported receiving training on BSF operation and maintenance
    - Observed method of drawing water for drinking, using a dipper
    - Using a deep well for water source
    - Reported cleaning water storage container
    - Treating water always or often

Key Lessons Learned:

- Biosand filters have a long lifespan and low breakage rate

Note: this was taken from a presentation by Mark Sobsey in Cambodia and has not been published as of the date of distribution (Electronic version available through CAWST)

UNC Health Impact Study in Cambodia (2007)

Kaida Liang, Mark Sobsey, Proum Sorya, & Mickey Sampson
Source: September 2007 Presentation in Cambodia

This was a longitudinal, prospective cohort study over a period of 5 months with a sample size of 208 households divided into 104 intervention households and 104 matched controls. Households were visited weekly to collect data on diarrheal disease rates and monthly to sample raw, treated and stored water. Water samples were tested for *E. coli* and turbidity.

The longitudinal study and health impact results were as follows:

- Filters showed on average a 95% reduction in *E. coli*- Up to 99.99% observed
- 55% of effluent water met the WHO's low risk criteria (<10 *E. coli* 100mL)
- 82% reduction in turbidity on average
- For all ages combined, there was a 44% reduction in diarrheal disease
- Greatest reduction in diarrheal disease was experienced by children ages 2-4 – 46%

Key Lessons Learned:

- Recontamination of filtered water is a barrier to achieving safer drinking water at the household level
- Need to design appropriate software (education) and hardware (containers) to prevent recontamination within the home

Note: this was taken from a presentation by Mark Sobsey in Cambodia and has not been published as of the date of distribution (Electronic version available through CAWST)

Evaluation of BSF Project in Danlí, Honduras (2007)

Kelly Miller; Undergraduate Student at University of Buffalo, NY
Prepared for Pure Water for the World, Honduras
(Electronic version available through CAWST)

This field evaluation was conducted in July and August of 2007 for Pure Water for the World, which has installed approximately 8,400 biosand filters in 135 communities. A random sample of 137 filters was drawn from 21 communities to represent the project area. Each household was visited and interviewed to determine use, maintenance, and perceived health benefits of the BSF. In addition, filters were inspected for quality of construction, flow rate, as well as sand and water quality. The household were visited a total of three times each to take stored and filtered water samples and test the subsequent samples for E. coli, turbidity and free chlorine levels.

The major findings of the evaluation were:

- 71.7% of filters were in use
- 95.6% of users reported no filter problems (1.5% of filters were changed b/c of a problem)
- 35% of users knew how to maintain filter
- Average flow rate of .77 L/min (minimum = .15 L/min, maximum = 1.37 L/min)
- 51% of filters were within 5-10 cm sand height range
- 75% (n=20) of filters tested for effective sand size fell within the recommended range
- 45% (n=20) of filters tested fall within recommended uniformity coefficient range

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Performance of BSF in Posoltega, Nicaragua- Field Evaluation (2007)

Jason Vanderzwaag; MASc Candidate in Civil Engineering at University of British Columbia
(Available at: http://www.civil.ubc.ca/pcwm/Seminars/Jason%20Vanderzwaag.pdf)

The study author investigated whether filters installed in Posoltega, Nicaragua in 1999 and 2004 were still in operation at the time of the study- 2007, looked at the long-term efficiency of Biosand filters, identified the socioeconomic factors and behavioural attributes associated with successful filter operation, and researched the tools available to households and communities to evaluate their own filters. To achieve the study objectives, the author conducted household interviews, collected observational data and performed water quality testing for source, filtered, and stored water in the households.

The study showed:

- 10% of the original filters were still in operation (n=260).

- Of the 90% of filters that were no longer in use, many were broken and cracked, families lacked filter maintenance and operation knowledge, and households did not have access to replacement parts to fix or repair the filter
- Household interviews showed that filter users liked the technology and would recommend it to others, thought the taste/odour and appearance of the filtered water was better, and thought the health of their family had improved after using the filter
- Recontamination of filtered water was substantial
- Average E. coli removal efficiency of the 27 filters in operation was 97%, ranging from 78% to 99.9%
- Lack of awareness, education and training contributed to poor maintenance and operation and recontamination of filtered water
- Poor filter construction appeared to affect sustained use more so than socioeconomic factors

Note: This was taken from a presentation at the University of British Columbia. The author has submitted this paper for publishing.

Cambodia Biosand Filter Monitoring and Evaluation Summary (2007)

Sustainable Cambodia & Rotary Club of Pursat, Cambodia
(Electronic version available through CAWST)

Sustainable Cambodia conducted a field evaluation six months after implementing a biosand filter project in Sthany, Osdau and Tnort Trat villages. The evaluation team interviewed 73 households over the course of 5 days and also completed observations of the biosand filter and safe water storage within each household. The results were compared to a baseline survey conducted just before biosand filter installation.

The results of the evaluation showed:

- 36% of households reported "treating" their drinking water after filtering – which method was unclear from the survey
- Households use filtered water for a variety of activities:
  - 99% drinking, 73% cooking, 48% cleaning vegetables, 44% washing dishes, 13% washing clothes, 1% bathing
  - At baseline, households treated only their drinking water
- An increase in the number of people treating their drinking water from 58% to 99% - households boiled their water before biosand filter
- 30% of filters had problems with the concrete - chipping or cracking
- 29% of filters had food stored inside the filter reservoir
- 22% of families did not have the filter lid in place – many because they never received lids
- Need more education about how the filter works and on safe storage

One tentative conclusion was that there was improved health after biosand filters had been installed. This was based on a household's perception that their overall health had improved, reporting reductions in diarrhea and typhoid. The recall period for baseline survey and evaluation were both long.

The project team will focus on education for operation and maintenance of the filter as well as safe storage and investigate the quality of cement used for filter body construction.

Sustained Health Impact by the Biosand Filter in Bonao, Dominican Republic: Evidence from (2005-2007)

Christine Stauber, Mark Sobsey
Source: March 2007 Press Release by University of North Carolina & WHO Household Water Treatment and Safe Storage (HWTS) Network Meeting in Ghana, May, 2008
(Results to be published in 2008)

This was a cross-sectional study that investigated the impact of biosand filters within 167 households in Bonao, Dominican Republic. During the four month baseline phase, weekly visits were made and biweekly water samples were collected. During the six month intervention phase, 80 homes were randomly selected to receive biosand filters. During the study, more than 5,900 weekly interviews and over 5,000 water samples were compiled.

The health impact results were as follows:

- Overall, the intervention reduced diarrhea in all ages including children under the age of 5 by 30-40%
- Biosand filter households experienced a 47% reduction in diarrheal disease on average
    - 60% reduction in dry season
    - 14% reduction in wet season
- Sustainability
    - 302/329 still using a biosand filter (92%)
    - This use ranged from 8-23 months
    - Of the households who were no longer using the filter – 63% (17/27) reported a poor perception or dislike of filtered water

A follow-up health impact study was conducted in 2007 that showed a 61% reduction in diarrheal disease for those households using biosand filters.

Note: this was taken from a press release by UNC and a presentation by Christine Stauber at the WHO HWTS Network Meeting in May, 2008 has not been published as of the date of distribution (Electronic version available through CAWST)

Project BRAVO Field Study (2006)

Derek Baker and William Duke
Source: CAWST Presentation and Executive Summary
Available at: http://www.cawst.org/assets/File/Project_BRAVO_Result_Summary.pdf
http://www.cawst.org/assets/File/BRAVO_Executive_Summary.pdf

This study was conducted in the Arbonite Valley of Haiti in 2005. The study team investigated biosand filter use and performance among long-term users of the biosand filter (1-5 years) and new users (0 to 3 months). Water quality samples were taken from both groups and tested for turbidity and *E. coli* removal. Households were also surveyed to determine the community acceptance level and perceptions of the filter. There were 80 households included in the new user sample and 107 households included as long-term users. A more in depth write up of the long-term users was included as a Category 1 study in this summary document and published in the Journal of Rural and Remote Health.

The major findings included:

- Average flow rate of the long-term users was .6 L/min and 1.5 L/min for new users
- Filter bacterial removal effectiveness was on average 98.5% for long-term users and 76% for new users

- High flow rate through the biosand filter was found to indicate poor bacterial removal effectiveness
- User perceptions were positive among both new and long-term users – easy to use, good smell and appearance of filtered water
- 95% of users thought their filtered water was "improved" as compared to unfiltered water
- 80% of users reported the health of their family had improved since drinking BSF water
- Filter is durable – no recurring costs to operate and maintain the BSF
- Strong need to maintain quality control of sand when installing the filters – sand must be properly tested, prepared, and monitored to assure optimum bacterial removal effectiveness
- Recontamination of filtered water was an issue in both long-term and new user households – safe water storage is critical

After analyzing the data from this study and field experience, CAWST Recommends:
- Sand media and flow rate monitoring
- Safe water storage to prevent recontamination
- Training Community Stewards/Promoters/Workers to influence hygiene and sanitation

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BSF Evaluation Report Samaritan's Purse – 6 Country Study (2002)

Nathan Kaiser, B.A., Kaida Liang, B.A., Marianne Maertens, B.Sc. Ryan Snider, B.A. M.Sc.
Conducted in Honduras, Nicaragua, Mozambique, Kenya, Cambodia, & Vietnam
Prepared for Samaritan's Purse Canada
(Electronic version available through CAWST)

This evaluation consisted of water analysis to determine fecal coliform removal on the biosand filter along with a user survey on almost 600 filters located in 6 countries on 3 continents. This study was done in the fall of 2001 and is the most rigorous study performed on the biosand filter.

A brief summary of the Evaluation is as follows:
- 98.4 % of all BSF recipients are using their filter on a regular basis.
- 93.0 % of fecal coliform in the source water is removed by the BSF.
- 88.5 % of all households surveyed uses their BSF every day.
- 85.0 % of the households surveyed report that they would be drinking their water directly from the source if they did not own a BSF.
- 98.1 % of the households surveyed report that the BSF has improved the health of their household.
- 5.0 % of the households surveyed ranks their health BEFORE receiving a BSF as excellent.
- 82.4 % of the households surveyed ranks their health AFTER receiving a BSF as excellent.

The WHO Drinking Water Guidelines state that there can be no E. coli present in any drinking water sample. A system that could purify water to its purest state would include a multiple step water treatment process. Although disinfection is an important component to any water treatment program, raw water can not be treated with disinfection. The BSF is an essential step in meeting the WHO drinking water guidelines. The BSF Evaluation of Samaritan's Purse projects discovered that the average fecal coliform removal rate under field conditions is 93%.

Average Fecal Coliform Removal Rates for the Individual Countries

Honduras	100 %
Nicaragua	99 %
Mozambique	98 %
Kenya	94 %
Cambodia	83 %
Vietnam	81 %
World Average (sample size = 577)	93%

Targeting Individuals: The Success of Household Sand Filtration (2000)

Adriaan Mol; MEDAIR East Africa - Project in Kenya
(Electronic version available through CAWST)

Random testing of 110 installed filters showed an average E. coli removal rate of 93%. It has to be mentioned that this average was brought down by 6 samples with a count of less than 80%, caused by owners misusing the filter. Excluding these samples an average removal rate of 96% was established, while in all but 11 cases turbidity was reduced to less than 5 NTU. Except for 17 cases, drinking water was produced with less than 10 E. coli per 100 ml.

CATEGORY 4 – ANECDOTAL REPORTS/STUDIES

Samaritan's Purse Project in Ethiopia (2006)

Source: Personal Communication

- Filters showed a 97% reduction in *E. coli* - many had very high contamination to start
- 80% reduction in turbidity
- 96.8% of the people using the filters after at least one year
- 94% know the maintenance when asked
- 48% cleaned the spout
- There was a 22% increase in handwashing (from 0% at the beginning) – so this shows that the hygiene is much harder to promote than using the filters
- 78% of the users stored the water safely

Key lessons learned:

- Education – software is critical to get better results
- Latrine construction requires more effort (were only able to be 2,800 pit latrines while they produced 7,500 filters - so many families still did not have latrines)
- Awareness of filter maintenance (spout cleaning) needs more emphasis

Note: this was an internal study by Samaritan's Purse; results will not be published and are not available.

PART 2: KANCHAN™ ARSENIC FILTER FIELD AND LABORATORY STUDIES

CATEGORY 1 – PUBLISHED PAPERS

Kanchan™ Arsenic Filter (KAF) Project in Nepal – MIT and ENPHO (2007)

Ngai, T., Shrestha, R., Dangol, B., Maharjan, M., & S. Murcott. "Design for Sustainable development – Household drinking water filter for arsenic and pathogen treatment in Nepal." Journal of Environmental Science and Health Part A. (2007) 42, 1879-1888.
Abstract available at:http://www.informaworld.com/smpp/content~content=a783095262~db=jour

Ngai, T.; Dangol, B.; Murcott, S.; Shrestha, R.R. *"KanchanTM Arsenic Filter – A Simple Solution for Arsenic Problem". Massachusetts Institute of Technology (MIT) and Environment and Public Health Organization (ENPHO).* Kathmandu, Nepal. ISBN: 99946-34-22-4. First edition. April 2005.
Available at http://web.mit.edu/watsan/worldbank_summary.htm

Ngai, T., Murcott, S., and Shrestha, R. *"KanchanTM Arsenic Filter (KAF) – Research and Implementation of an Appropriate Drinking Water Solution for Rural Nepal." Paper to the 9th Forum on Arsenic Contamination of Groundwater in Asia, Asia Arsenic Network and Research Group of Applied Geology.* Japan. November 20-21, 2004.
Available at http://web.mit.edu/watsan/Docs/Other%20Documents/KAF/Ngai%20-%20Asia%20Arsenic%20Network%20symposium%20paper%202004.pdf

This project was funded by the World Bank Development Marketplace Global Competition 2003 and implemented as well as evaluated by Massachusetts Institute of Technology (MIT), USA and the Environment and Public Health Organization (ENPHO) of Nepal.

Over 2500 Kanchan™ Arsenic Filters were distributed by various agencies during the project period. Three versions of the KAF were distributed, namely concrete (over 900 units), Hilltake plastic (over 600 units), and Gem505 plastic (over 1000 units). Almost all of these filters are used by households affected by arsenic contamination in their drinking water.

Two rounds of "blanket" monitoring of all existing filter were conducted. The first round monitoring took place between February 2004 to May 2004. The second round took place between Dec 2004 to February 2005.

Parameters monitored during the first round including arsenic removal, iron removal, pH, flow rate, phosphate concentration, as well as GPS location, household demographic, filter cleaning frequency, filter usage rate, and user feedback.

Arsenic removal was found to be excellent. Of the 966 filters tested for arsenic during round 1, over 95% of them were able to meet the Nepali arsenic interim standard of 50 ug/L. The average arsenic removal is in the range of 90-95%. The filters that showed unsatisfactory arsenic removal were later found to be defective. The filters were either installed incorrectly (e.g. use of incorrect sized sand and gravel), or improperly operated and maintained by the users.

Round 1 KAF monitoring results – Arsenic removal (n=966)

Effluent Arsenic Concentration (ug/L)

Influent Arsenic Concentration (ug/L)	ND	10	20	30	40	50	60	70	80	90	100	150	200	250	300	350	400	450	500
500	5	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
450	8	1	2	3	0	0	0	0	0	0	1	0	0	0	1	1	1	3	
400	10	2	2	1	2	0	0	0	0	0	0	1	0	1	0	0	1		
350	15	3	1	3	1	0	0	0	0	0	0	0	0	0	0	0			
300	28	1	3	1	1	0	0	0	0	0	0	0	0	1	0				
250	27	2	1	2	2	2	0	0	1	0	0	0	1	2					
200	32	1	0	0	0	0	0	0	1	0	1	0	2						
150	40	1	1	0	1	0	0	0	0	0	0	1							
100	99	8	3	1	1	0	0	1	0	0	0								
90	86	6	3	0	0	0	1	2	0	1									
80	57	1	0	1	0	0	0	0	0										
70	42	3	0	3	0	0	0	0											
60	34	13	5	2	1	0	0												
50	71	5	2	0	0	0													
40	21	2	0	0	0														
30	17	0	0	0															
20	44	1	0																
10	12	0																	
ND	189																		

Figures indicate number of filters

Iron removal was also excellent. The average iron removal efficiency is about 90-95%. A few filters were unable to significantly remove iron. They were later found to be defective in the installation process as well.

Round 1 KAF monitoring results – Iron removal (n=953)

Effluent Iron Concentration (mg/L)

Influent Iron Conc. (mg/L)	ND	0.1	0.3	0.5	1	2	3	5	10
10	17	1	42	0	62	1	13	6	1
5	47	1	73	0	45	1	1	0	
3	69	0	11	0	1	0	0		
2	32	0	0	0	1	0			
1	210	0	1	0	0				
0.5	26	0	0	0					
0.3	193	0	2						
0.1	2	0							
ND	94								

Figures indicate number of filters

The arsenic monitoring results during the round 2 monitoring round is unavailable at this moment. However, preliminary users feedback is tabulated below.

Round 2 KAF monitoring results – Users Feedback (n=424)

	Yes	*Partially*	*No*
Filter still in operation after 1 year	85.3%	8.3%	6.3%
Users think filter operation is easy	73.6%	---	26.4%
Users can operate the filter correctly	50.2%	42.3%	7.4%
Users will recommend filter to others	82.5%	---	17.5%

	Better	*Same*	*Worse*
Appearance of filtered water	92.8%	6.9%	0.2%
Taste of filtered water	95.0%	5.0%	0%
Smell of filtered water	89.9%	11.1%	0%
Users' perceived health conditions after drinking filtered water	77.5%	22.5%	0%

CATEGORY 2 – HIGH QUALITY UNPUBLISHED PAPERS

4 Week Daily Study on Total Coliform Removal of the KAF (2005)

Dipina Sharma
Source: Bachelor of Science Thesis- Kathmandu University
Available at http://web.mit.edu/watsan/worldbank_summary.htm

- Installed 5 KAF (plastic Gem505 version) in the village of Kasiya of Nawalparasi districts of Nepal
- 40 L of tube well water poured into each filter per day
- Tested total coliform removal over a 4-weeks period using membrane filtration technique
- 4 of the 5 filters achieved 96-100% total coliforms removal within 3 weeks since installation, of which one filter achieved 100% total coliform removal in just 9 days.
- The remaining one of the 5 filters shows unsatisfactory total coliform removal is believed to be related to insufficient sand cleaning.
- The use of a clean storage container and good hygiene practise was found to improve filtered water quality.

Can Iron and Arsenic Particles Migrate through the KAF Sand Layer? (2005)

Bardan Ghimire
Source: Masters Thesis, Kathmandu Universit
Available at http://web.mit.edu/watsan/worldbank_summary.htm

- Two older concrete filters (12-months of operation) and two newer concrete filters (5-months of operation) in the Terai region of Nepal were studied.
- Sand samples were collected at every 4 cm interval from the top to the bottom of the sand layer.
- Arsenic and iron concentrations on these sand samples were tested using laboratory AAS method.
- Iron and arsenic appear to be effectively trapped on top of the fine sand
- The low and similar iron and arsenic values found in the region 5cm or lower appear to be background concentration
- The significantly lower arsenic-to-iron ratio at 5cm depth or lower further confirms that arsenic-loaded iron particles are NOT migrating down through the sand media
- The similarity in the profiles of older (12-months) and newer (5-months) filters suggest that the profiles may not change over time

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Arsenic, Iron and Coliform Removal Efficiency of KAF (2004)

Prem Krishna Shrestha
Source: Masters Thesis, Tribhuvan University, Nepal
Available at http://web.mit.edu/watsan/worldbank_summary.htm

- Tested arsenic, iron, and coliforms removal of the KAF Gem505 version through 3 rounds of study.
- Phase I laboratory study used groundwater from Kathmandu spiked with arsenic
- Phase II laboratory study used tap water from Kathmandu spiked with arsenic

- Phase III field study used naturally occurring arsenic-contaminated water in the Terai region of Nepal.
- Phase I study found that arsenic removal is less than 50% because of phosphate interference. Phosphate in the Kathmandu groundwater was 31 ppm.
- Phase II study found that arsenic removal is 85%. Phosphate concentration in Kathmandu tap water is only 0.4 ppm.
- Phase III study found that for naturally-occurring groundwater contaminated by arsenic, the arsenic removal is the best, at 91%.
- Laboratory study shows 94% removal of total coliform

KAF Study on Effect of Air Space between the Resting Water and the Diffuser Basin (2004)

Shashank Pandey
Source: Bachelors Thesis, Kathmandu University, Nepal
Available at http://web.mit.edu/watsan/worldbank_summary.htm

- 4 KAF Hilltake versions located in a rural village of Nawalparasi district were studies
- Raw water of 250 ppb arsenic was poured into the filter for 4 cycles
- Filtered water was continually collected and monitored (one sample for every 2L filtered)
- Research found that there is no fluctuation in arsenic concentration within short timeframe.
- The arsenic concentration is either non-detect or 10 ppb in majority of the filtered samples.
- Research suggests that arsenic removal is happening at two locations – adsorption on iron nails in the diffuser box, and adsorption on iron particles accumulated on the fine sand

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Performance Evaluation of the Arsenic Biosand Filter for Mitigation of Arsenic Contamination (2004)

Naomi Odell; US Peace Corps volunteer - Parasi, Nepal, April 2004
(Available at http://web.mit.edu/watsan/worldbank_summary.htm)

- Two concrete version of the KAF were studies in the rural town of Parasi.
- One filter has 2.5 kg of iron nails
- One filter has 5.0 kg of iron nails
- Study recommended the use of 5.0 kg of iron nails for effective arsenic removal
- Over 95% of arsenic can be removed in the KAF with 5.0 kg of iron nails.
- 4-months is too short a time to observe any noticeable decrease in iron nails' arsenic adsorption capacity

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Arsenic Biosand Filter: Design of an Appropriate Household Drinking Water Filter (2003)

Tommy Ngai and Sophie Walewjik
Source: Final Report Submitted to Massachusetts Institute of Technology in July 2003. Available at http://web.mit.edu/watsan/worldbank_summary.htm

- Pilot study -16 concrete filters in 4 rural villages (Nawalparasi and Rupendehi districts) installed in Oct 2002.
- Evaluation in Jan 2003 showed :

Technical Indicator	Range	Average Results
Arsenic removal	87 to 96%	93%
Total coliform removal	0 to >99%	58%
E. Coli removal	0 to >99%	64%
Iron removal	>90 to > 99%	>93%
Flow rate	4 to 23 L/hr	14 L/hr

PART 3: SUMMARY TABLES OF FIELD AND LABORATORY STUDIES

Table 1: Biosand Filter Field and Laboratory Tests

Country	Author(s)	Organization(s)	Year	Type of Study	Category †	Key Lessons Learned
-	Sobsey, M. Stauber, C. Casanova, L. Brown, J. Elliott, M.	University of North Carolina	2008	Literature Review & Technology Comparison	1	• Biosand filters are an effective form of HWT • Greatest potential for widespread use and adoption for sustained use and health impact
-	Elliott, M. Stauber, C. Koksal, F. DiGiano, F. Sobsey, M.	University of North Carolina	2008	Laboratory	1	• BSF performed best when less than one pour volume (18.3 L) was poured into filter and after about 30 days of filter ripening
-	Baumgartner, J.	Harvard School of Public Health; Massachusetts Institute of Technology (MIT)	2007	Laboratory	1	• Encourage users to filter 5 L of water at a time • When filtering more than 5 L at a time, use first five liters for consumption and the remainder for other household needs
Dominican Republic	Stauber, C. Elliott, M.	University of North Carolina	2006	Field Study	1	• Ripening time of filter varies, probably due to influent water quality • 95-98% reduction of *E. coli* in a ripened filter
Haiti	Duke, W. Baker, D.	University of Victoria, BC; CAWST	2006	Cross-sectional evaluation	1	98.5% removal of E. coli on average in sample of 107 filters

† Category Key

1 - Peer reviewed, published papers; 2 - High quality, unpublished papers; 3 - Informal reports (field study, PowerPoint presentation, press release, personal communication); 4 - Anecdotal reports/studies

Country	Author(s)	Organization(s)	Year	Type of Study	Category †	Key Lessons Learned
Kenya	Fewster, E. Mol, A.	Medair	2004	Cross-sectional evaluation	1	• 70.5% of filters achieved 0-10 faecal coliforms per 100 mL • 82.4% of filters achieved <10 NTU for turbidity
-	Palmateer, G. Manz, D.	National Water Research Institute Canada	1997	Laboratory	1	• 83% removal of heterotrophic bacterial populations, • Removed 100% of Giardia cysts • Removed 99.98% of Cryptosporidium oocysts • Removed 50-90% of organic and inorganic toxicants
Ethiopia	Earwater, P.	Cranfield University Silsoe	2006	Cross-sectional evaluation	2	Quality of maintenance, lack of educational message reinforcement and lack of support provided to filter users contributed to low usage and poor filter performance in some villages
Nepal	Lee, T. Paynter, N.	MIT	2001	Cross-sectional	2	• 83% removal of E. coli in a sample of 38 filters • 23% of filters were found to be in poor condition – diffuser plate problems, incorrect resting water level, or immature biofilm
-	Buzunis, B.	University of Calgary	1995	Laboratory	2	• First laboratory study of intermittent slow sand filter • Fecal coliform removal efficiency of 96% and turbidity removal efficiency to <1 NTU

† Category Key

1 - Peer reviewed, published papers; 2 - High quality, unpublished papers; 3 - Informal reports (field study, PowerPoint presentation, press release, personal communication); 4 - Anecdotal reports/studies

Country	Author(s)	Organization(s)	Year	Type of Study	Category †	Key Lessons Learned
Nicaragua	Manz, D. Buzunis, B. Morales, C.	University of Calgary	1993	Field evaluation	2	Original BSF study showed intermittent slow sand filter has high removal efficiency in 55 filters
Cambodia	Liang, K. Sobsey, MD	University of North Carolina	2007	Cross-sectional evaluation	3	• Biosand filters have a long lifespan and low breakage rate • Need to design appropriate software (education) and hardware (containers) to prevent recontamination within the home
Honduras	Miller, K.	Pure Water for the World	2007	Cross-sectional evaluation	3	• 74.1% of filters still in use • 35% of users knew how to properly maintain the filter
Nicaragua	Vanderzwaag, J.	University of British Columbia	2007	Field evaluation	3	• 10% of the original filters were still in operation (after 1999 & 2004 installation) • Lack of awareness, education and training contributed to poor maintenance and operation and recontamination of filtered water
Haiti	Baker, D. Duke, W.	CAWST	2006	Field Evaluation	3	• High flow rate through BSF found to indicate poor bacterial removal effectiveness • Need to maintain quality of sand media to ensure effective BSF • Recontamination is an issue

† Category Key

1 - Peer reviewed, published papers; 2 - High quality, unpublished papers; 3 - Informal reports (field study, PowerPoint presentation, press release, personal communication); 4 - Anecdotal reports/studies

Country	Author(s)	Organization(s)	Year	Type of Study	Category †	Key Lessons Learned
Kenya, Mozambique, Cambodia, Vietnam, Honduras, Nicaragua	Kaiser, N. Liang, K. Maertens, M. Snider, R.	Samaritan's Purse Canada	2002	Cross-sectional evaluation	3	• Average fecal coliform removal rate across all 6 countries was 93% in sample of 577 filters • 88.5% of households used filter everyday • O&M info to users needs to be improved - additional follow-up visits and increased frequency of visits
Kenya	Mol, A.	Medair	2000	Cross-sectional evaluation	3	• Random testing of 110 filters showed E. coli removal rate of 93% • 90% of samples turbidity <5 NTU
Ethiopia	-	Samaritan's Purse	2006	Cross-sectional evaluation	4	• Education – software is critical to get better results • Awareness of filter maintenance (spout cleaning) needs more emphasis

† Category Key

1 - Peer reviewed, published papers; 2 - High quality, unpublished papers; 3 - Informal reports (field study, PowerPoint presentation, press release, personal communication); 4 - Anecdotal reports/studies

Table 2: Biosand Filter Health Impact Studies

Country	Author(s)	Organization(s)	Year	Type of Study	Category †	Key Lessons Learned
Cambodia	Liang, K. Sobsey, MD	University of North Carolina	2007	Longitudinal, prospective cohort study	3	• For children under 5 and adults, there was a 44% reduction in the number of cases of diarrhea • Greatest reduction occurred in children ages 2-4 - 46% reduction
Dominican Republic	Stauber, C. Sobsey, MD	University of North Carolina	2006	Longitudinal, prospective cohort study	3	• On average, there was a 47% reduction in the number of cases of diarrhea • 60% reduction during the dry season • 14% reduction during the wet season • 92% of households were still using the filter 8-23 months after receiving it • Those that were no longer using the filter cited dislike of filtered water

† Category Key

1 - Peer reviewed, published papers; 2 - High quality, unpublished papers; 3 - Informal reports (field study, PowerPoint presentation, press release, personal communication); 4 - Anecdotal reports/studies

Table 3: Kanchan™ Arsenic Filter Field and Laboratory Studies

Country	Author(s)	Organization(s)	Year	Type of Study	Category †	Key Lessons Learned
Nepal	Ngai, T. Dangol, B. Murcott, S.	Massachusetts Institute of Technology (MIT) ENPHO World Bank	2005	Cross-sectional evaluation	1	• 95% of 966 filters met the Nepali arsenic interim standard • Average arsenic and iron removal efficiency was in the range of 90-95% • 85.3% of users were retained after 1 year
Nepal	Sharma, D.	Kathmandu University	2005	Laboratory	2	Removal of total coliforms in 5 filters showed 4/5 filters removed 96-100%
Nepal	Ghimire, B.	Kathmandu University	2005	Laboratory	2	• Iron and arsenic appear to be effectively trapped on top of the fine sand in 4 filters (2 old, 2 new)
Nepal	Shrestha, PK	Kathmandu University	2004	Laboratory	2	• Arsenic removal is the best for naturally-occurring groundwater contaminated with arsenic, at 91% • Laboratory study shows 94% removal of total coliform
Nepal	Pandey, S.	Kathmandu University	2004	Field study	2	Arsenic removal is occurring at two locations – adsorption on iron nails and on iron particles accumulated on the fine sand
Nepal	Odell, N.	US Peace Corps	2004	Field study	2	• Over 95% of arsenic can be removed in the KAF with 5.0 kg of iron nails • Recommend use of 5.0 kg iron nails
Nepal	Ngai, T. Walewjik, S.	MIT	2003	Field study	2	• Arsenic removal on average 93% in 16 pilot filters • Iron removal - >93% on average

† Category Key

1 - Peer reviewed, published papers; 2 - High quality, unpublished papers; 3 - Informal reports (field study, PowerPoint presentation, press release, personal communication); 4 - Anecdotal reports/studies