Evaluation of the Biosand Filter for Reducing Risks of Diarrheal Illness and Improving Drinking Water Quality in Communities of The Dominican Republic

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Introduction

Water is not only a basic need for life but also a human right according to the UN. Consumption of unsafe water causes gastrointestinal illnesses that kills more than 2 million people annually. However, developing safe, piped potable water supplies and systems is an important international health goal that will take decades to achieve. In the meantime, more than one billion people worldwide, including a large segment of the population of the Dominican Republic, remain without access to improved, safe water. There are pressing needs in the Dominican Republic and many other developing countries to improve such access and thereby reduce the global burden of waterborne disease.

Recent evidence documents that simple and low-cost household interventions alone can provide safe water and greatly decrease the burden of diarrheal disease. For example, chlorination of household water in a dedicated storage container can reduce microorganisms by >99% and reduce diarrheal illness by 44%. Another technique proven to reduce waterborne microorganisms and disease is "solar disinfection" or SODIS, in which water is placed in a clear, plastic beverage container and exposed to sunlight for several hours. These approaches have been effective for improving the quality of the water consumers' use in homes and communities and have been implemented in various parts of the world. Furthermore, these household drinking water interventions have proven so effective that an international network to promote household treatment and storage has been created through the World Health organization to support the study and dissemination of existing and developing technologies.

While interventions such as chlorine and solar disinfection have been successful in the field, there are limitations to these forms of household water treatment. Chlorination is not effective against some important waterborne pathogens such as the intestinal parasites *Cryptosporidium parvum*, *Giardia lamblia* and *Entamoeba histolytica*. Parasites such as Giardia and *Entamoeba* are considered to be major causes of diarrheal illness in the Dominican Republic. An important limitation of solar disinfection is the small quantity of water that can be disinfected in one bottle, requiring the cumbersome use of multiple bottles to serve a typical household. Furthermore, both chlorination and solar disinfection are much less effective and sometimes ineffective in waters with higher turbidity and color. To address some of these limitations, there has been a growing interest in filtration methods that can reduce turbidity and color, remove parasites such as *Cryptosporidium, Giardia and Entamoeba* and conveniently produce abundant quantities of water, thereby overcoming some of the limitations of the other household water treatment techniques.

Various filtration methods for reducing microbes in water have been widely known and practiced for decades and new ones continue to be developed and evaluated. For example, sari cloth has been used to filter out *Vibrio cholerae* bacteria associated with plankton in raw water. However, it is not effective in removing individual bacteria or viruses. Ceramic or clay pot filters also have been widely used for household drinking water filtration. However, the amount of water produced by many ceramic filters is relatively small compared to daily household needs, the filters require regular and rigorous cleaning to avoid clogging and they can be easily broken or damaged.

A recent innovation for household water treatment is an intermittently operated, slow sand filter (SSF) that does not require backwashing or replacement of the sand. Slow sand filtration is a biological process in which removal of turbidity (particles), microbes and biodegradable organic matter occurs due to a biological slime layer that develops within the top few centimeters of sand. Slow sand filters have long been known to extensively reduce pathogens in water but have not been widely applied to non-piped and household drinking waters. This is because previous designs required continuous flow operation and replacement of the sand (during which time the filter was taken out of operation, thus requiring more than one filter unit).

Recently, Dr. David Manz of the University of Calgary developed a household version of slow sand filtration, called the Biosand filter (BSF). Unlike other granular medium filters or SSFs, this slow sand filter can be operated intermittently and does not require either periodic replacement of the top few centimeters of sand or backwashing. This adaptation of the slow sand filter design makes it practical to operate and use in the home, analogous to the simple but expensive "pour through" pitcher filters now widely used in households in developed countries. Preliminary studies on the BSF document bacterial reductions both in the laboratory and in the field. For example, researchers at MIT found 99.5% removal of total coliform bacteria in a study in Nepal. Laboratory studies at UNC indicate about 99% reduction of E. coli. Studies in a Canadian lab report > 99.9% removal of protozoan parasites. While these studies demonstrate effective removal of some pathogenic microorganisms, there are still major concerns about the ability of the BSF to remove waterborne viruses and other pathogens as well as its ability to reduce waterborne diarrheal illness among users. The latter has not been rigorously studied at all. Therefore, further evaluation of the BSF, especially in the field, is a critical need in determining if it is an appropriate and effective technology for household water treatment.

While the BSF may remove microbes from water, the filter provides no assurance that the water will not become re-contaminated during storage and use in the home. It is generally recommended that water from the BSF be stored in a narrow mouth container that can be protected from re-contamination due to the use of dirty dipping devices or even hands to remove water. Furthermore, people have been known to transfer BSF filtered water from the collection container to other containers, introducing opportunities for recontamination. Numerous studies document that water gathered and even pre-treated for use in the home can become re-contaminated during storage and use if it is not stored in a protected or "safe" container (usually having a narrow mouth for filling and cleaning and a spigot or spout to dispense stored water) and if it does not contain a protective level of chlorine of other chemical disinfectant residual. Therefore, many systems to physically remove microbes from water are also accompanied by the

use of a chemical disinfectant such as chlorine (typically hypochlorite or hypochlorous acid). Indeed, the use of such chlorine along with a safe storage container is the basis of the CDC Safewater system. Therefore, it is useful to consider a the implementation of a multi-barrier system of household water management consisting of the BSF filter, followed by chlorination of the filtered water and storage of the chlorinated water in a protected or safe container.

Study Objectives

The objectives are to conduct a prospective, longitudinal field study of the microbial efficacy and health impact (reduction in household diarrheal disease) of the Biosand filter system for drinking water treatment in selected Dominican Republic communities and households. The study design will be patterned on the randomized intervention designs previously used by the US Centers for Disease Control and Prevention (CDC) for the household chlorination and safe storage system now known as the CDC Safewater system.

The proposed study design will involve recruitment and participation of approximately equal numbers of matched sets of households: (1) those given the Biosand filter with a safe storage vessel, (2) those given the Biosand filter with a safe storage vessel as well as hypochlorite solution to add to the filtered water, and (3) those using only the prevailing household drinking water systems (without the Biosand filter and chlorination systems). These households will be followed to determine the microbiological quality of their drinking water and the levels of household diarrheal disease (based on data gathered using a questionnaire). The effectiveness of the Biosand filter used alone and in conjunction with free chlorine will be quantified on the basis of reducing microbes in drinking water and reducing diarrheal disease among Biosand filter and Biosand filter-chlorine users relative to the microbial quality of water and levels of diarrheal illness in the matched control households.

Developing the scientific evidence for the performance of the BSF with and without chlorination will be done within the context of delivering water, sanitation and hygiene (WSH) interventions to the participating households. The approach will include mobilization, information and education, with involvement of the local communities and their available systems and partners (health clinics, community groups, schools, religious organizations, NGOs, local government agencies, etc.), involvement of the micro-entrepreneurs who make and distribute filters, development and dissemination of educational materials about the BSF as well as basic hygiene and sanitation, and the development and use of a sustainability system or model for the water, sanitation and hygiene program. Eventually all households will get all of the WSH interventions, but some will not initially get the Biosand filter or Biosand filter with chlorine due to the practical limitations of furnishing the filters and chlorination system to all of the households at the same time.

Justification and Rationale for BSF Field Research in the DR, Contacts and Affiliations

The Dominican Republic (DR) provides an ideal location and situation to test the BSF for its ability to improve household drinking water quality and reduce waterborne diarrheal disease. Safe water supplies are lacking in many communities in the Dominican Republic, and many people in both suburban and rural areas must manually gather and use untreated water for their households. The need to improve access to safe water in the Dominican Republic has already been recognized and in fact, there are currently thousands of Biosand filters being used in many

areas of the country. This recent introduction of the BSF was made possible by NGOs, such as Rotary Clubs.

There is now a large network of stakeholders and others in the Dominican Republic interested in supporting or encouraging a research and demonstration project to scientifically evaluate the performance of the BSF in Dominican Republic communities and their households. A number of seminars, workshops and other activities to address water quality and health issues have been held in various communities of the Dominican Republic. Currently, the Peace Corps and various Rotary Clubs are working together to supply filters and chlorine with education in their use to hundreds of households. This effort to introduce BSF or BSF-chlorine for household water treatment is an important contribution in the effort to provide safe water to those who lack it. However, scientific evidence is needed to determine if water treated by the BSF or the BSF plus chlorine-chlorine, within a supporting water, sanitation and hygiene intervention system, is resulting in the consistent production of household drinking water with high microbiological quality that is of low risk from waterborne disease and therefore, really safe. Without such scientific evidence from carefully designed and conducted field studies, there is no assurance that the BSF or the combination of BSF-chlorine is actually working. Such a scientific study is proposed herein

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Research Questions to be Examined and Research Methods to be Used

Can the Biosand filter, in combination with safe storage or in combination with chlorination and safe storage and supported by water, sanitation and hygiene education, provide users with a an effective, reliable and sustainable system for producing household water of safe microbial quality reduced risk of waterborne diarrheal illness in communities in the Dominican Republic?

Approach, Tasks and Methods

Community Selection, Recruitment, Education and Participation

The study will be conducted in one or more communities that either lack access to piped water, have unsafe piped water or both. Communities will be contacted and recruited with the assistance of regional and local entities, including health clinics, NGOs, local or regional institutions of higher education, relevant water resources agencies, filter makers and purveyors of chlorine, and other community resources including schools, major employers and religious institutions. These institutions and their members will be used to mobilize community support and will serve as entities through which to establish and implement activities to gain community participation in the water, sanitation and health system of which the household water treatment technologies are an integral part. Workshops, focus groups and other communication systems will be used as mechanisms to promote health awareness, education and understanding, including water hygiene and treatment, to provide the foundation for the presence of the project within the community and to develop the tools and carry out the various activities of community participation in the study. Community households will be allocated, preferably by a random process, into control and intervention (BSF-storage container and BSF-storage container-chlorine) households.

Determining Microbial Quality of Water and Microbial Reductions by the BSF and BSF-Chlorine

One task of the study is to quantitatively determine the microbiological quality of household drinking water and the treatment efficiency of the Biosand filter and the Biosand filter plus chlorine for producing household drinking water. Water samples will be collected and analyzed bi-weekly from the selected study households, including those using the Biosand filter technology those using the Biosand filter plus chlorine and those of control households not using the BSF or BSF-chlorine (i.e., normal household water practice) in the study communities. Treated and untreated water samples will be analyzed for fecal indicator microorganisms to assess microbial quality and to determine reductions by the BSF and BSF-chlorine treatments. Indicator organisms of fecal contamination are easier and cheaper to analyze than pathogens and are considered reliable in estimating pathogen reductions. The test microorganisms that will be detected and quantified are: total coliform and *E. coli* bacteria. Other water quality parameters to be measures are: pH, temperature, turbidity, and chlorine levels (some household water sources will be using chlorine). Household water supplies will be sampled over a sufficient period of time to account for the effects of seasonal variability of water quality and the impacts of periodic rainfall events that typically degrade water quality. The levels of fecal indicator microbes and other water quality parameters will be compared in untreated and BSF-treated and BSF-chlorine-treated household water to determine the extent of reduction by the treatments (on a percentage and $\log_{10}$ basis). In addition, the quality of household water will be similarly compared between control households (untreated water only) and in BSF and BSF-chlorine households (both untreated and treated waters).

Various measures will be used to determine the extent of compliance with the household water treatment interventions. These measures will include sanitary inspections of the household water systems and several measures of water storage and usage within control and intervention households, such as water storage practices and estimates of daily water usage for drinking and other household purposes. Questionnaires and other survey instruments will be used to determine the level and extent of use of the water treatment interventions and the level of successful or acceptable use.

It is expected that the quality of untreated water of control and intervention households will be similar, based on levels of microbes and other water quality parameters. It is also expected that the quality of BSF- and BSF-chlorine- treated household water will be significantly better than that of the untreated water of both intervention and control households. It is further expected that the quality of untreated water in control households will be further reduced during storage due to unsanitary storage and handling practices (a well-documented observation from previous studies). These comparisons of water quality will be made quantitatively using either parametric or non-parametric statistical methods. In addition, the quality of household water will be evaluated against the relevant microbial and turbidity quality standards of the Dominican Republic based on how often (as a percentage) the water meets DR quality standards. It is anticipated that BSF-treated and BSF-chlorine-treated water will meet microbial and turbidity quality standards much more frequently than does the untreated water.

Reduction of Diarrheal Illness

The study households with and without the treatment interventions also will be monitored for levels of diarrheal disease and these data will be analyzed to determine the extent of reduction of diarrheal illness by the treatment interventions. Biweekly interviews of a reporting person from each household will be conducted by a trained questioner from the community using a pre-tested questionnaire. Baseline data on socio-economic status as well as health and hygiene information on the households in the study will be gathered by healthcare workers who are part of the study team and who work within the community. The households will be compared in order to determine if there are any differences among them that may have an affect on diarrheal illness prior to the use of the BSF or BSF-chlorine technologies. To determine differences in diarrheal illness, weekly or bi-weekly diarrhea surveillance will be performed. A pre-tested, structured questionnaire will be used in the assessment of prevalence and incidence of diarrheal illness during the study period. This questionnaire will be constructed with the help of Dominican researchers as well as the communities involved in the study. Comparisons of the results of the questionnaire will be made quantitatively using either parametric or non-parametric statistical methods to assess the risk of diarrheal illness in households with and without the BSF or BSF-chlorine technologies. It is anticipated that households with and without the treatment technologies will be similar in number of people per household, source water quality, and other factors known to affect risk of diarrheal illness. It is further anticipated that the households with the BSF and the BSF-chlorine will experience significantly less diarrhea than the control households who practice conventional methods of household water management.

Expected Overall Study Outcomes

Overall, the expected outcomes of this study are that BSF and BSF-chlorine treatment of water at the household level will greatly improve the microbial quality of household drinking water and that the water will typically meets Dominican Republic standards for microbial quality and turbidity. It is further expected that the systems for introducing these technologies within a WSH system supported by education and community participation will provide a solid foundation that allows for sustained practice and further dissemination of the system to other communities. Furthermore, it is anticipated that the members of households with these water treatment interventions (BSF alone or BSF plus chlorine) will experience a significantly reduced burden in diarrheal illness. This outcome will provide a sound scientific basis for further promotion and dissemination of the BSF and the BSF plus chlorine as simple and affordable technologies throughout the DR and in other developing countries. The project is proposed to begin in late 2004 and end in late 2005.

Results of the Research

Upon completion of the research in the field and the analysis of the data, we plan to share this information with the community, with various other stakeholders, such as government officials, NGO and micro-entrepreneurs who make filters and sell chlorine in the Dominican Republic. We also plan to share the results with the relevant international health organizations, including various NGOs such as Rotary International, the International Network to Promote Safe Household Water Treatment and Storage and the World Health Organization. In addition, we plan to present the results at national and international scientific meetings and we intend to publish them in peer-reviewed scientific journals.

Project leader

Mark Sobsey is professor of environmental microbiology in the Department of Environmental Sciences and Engineering, School pf Public health, University of North Carolina at Chapel Hill. He has conducted numerous field and laboratory studies on water quality and on water sanitation and hygiene, including health impact studies and risk assessment. he has advised numerous graduate students and post-graduate fellows who have performed both lab and field research on water quality and health, including field water quality and health intervention studies abroad (e.g., Bolivia, Bangladesh and The Philippines). Professor Sobsey represents his university as a member of the International Network to Promote Safe Household Water Treatment and Storage, he is an advisor to the World Health Organization, and he is in close contact with various organizations and stakeholders interested in projects such as this one. He can help disseminate the information to the relevant international health agencies and other organizations and stakeholders.

Project Budget

The estimated costs to conduct this study are between US$200,000 and 250,000. This includes all costs for personnel (salaries, wages and fringe benefits), facilities, equipment, materials, supplies, transportation, communication and indirect costs. Further details, of costs including a detailed budget of estimated expenses can be provided on request.