Pathogen removal and use of biosand water filters in the Region Autonoma Atlantico Sur of Nicaragua

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Pathogen removal and use of biosand water filters in the Región Autónoma Atlántico Sur of Nicaragua

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This study examined usage of biosand filters amongst 86 families in three different communities in the Región Autónoma Atlántico Sur (RAAS) of Nicaragua. 75% of the families in the study were actively using their filter whilst the remaining 25% no longer used their filter. Pathogen levels (thermotolerant coliforms) were examined in samples of the unfiltered source water, the filtrate and the stored water post-filtration. Average pathogen removal efficiency was 89% and was not significantly higher amongst families who followed the recommended patterns of use of the filter. While the filters in the study typically produced water that was considered safe to drink, recontamination of the stored, filtered water was a significant problem that occurred in 66% of the families. This study affirms the effectiveness of biosand water filters in the field and highlights the need for a focus on prevention of recontamination of the stored, filtered water.

Introduction

Setting

The communities of the Región Autónoma Atlántico Sur (South Atlantic Autonomous Region, RAAS) of Nicaragua lack access to adequate water and sanitation facilities. Bluefields, the largest city in the RAAS has approximately 50,000 inhabitants, the majority of which source their drinking water from shallow, private, hand-dug wells, or from deeper communal wells supplemented by rain water collection tanks during the wet season. Less than 50% of the houses in Bluefields are connected to septic tanks and a high number of families use unimproved latrines, many of which 'hang' directly over the Bluefields Bay or small water courses (Gamo and Canadas 2009). The remote community of Kahkabila is located on the Laguna de Perla (Pearl Lagoon) approximately 45 km north of the city of Bluefields, while Monkey Point is located approximately 40 km south of Bluefields on the Caribbean Sea. Both communities are multi-ethnic, multi-lingual communities that are accessed by boat from Bluefields. The climate of the region is hot and humid, characteristic of other tropical regions in the Caribbean. The area has a very high average annual rainfall of 4400 mm/yr (Gamo & Canadas, 2009), which, combined with the presence of traditional, unimproved pit or hanging latrines and poorly functioning septic tanks has lead to a very high incidence of shallow groundwater contamination.

In response to the poor levels of access to safe water and sanitation in the RAAS, blueEnergy, a local non-government organisation based in Bluefields initiated a water and sanitation program in 2009. This program is focused on working with families to provide biosand water filters for household water treatment, drilling drinking water wells (Baptist wells), hygiene training and installation of dry latrines. Biosand water filters, developed at the University Calgary, Canada in the 1990's are an adaption of traditional slow sand filters for household water treatment. Biosand filters remove pathogens and suspended solids from water through a combination of biological and physical processes that take place within biological zones and the sand layer within the filters (CAWST 2010). In blueEnergy's biosand filter program, a trained biosand filter promoter visits families within neighbourhoods where levels of access to safe drinking water sources are particularly low, to discuss biosand filters and invite the interested families to participate in the program. A representative from each interested family then attends a half day training session that covers hygiene, sanitation, safe drinking water and use of biosand filters. A family member then returns the following week to construct their concrete filter (over one day, including washing the sand) in blueEnergy's workshop under the guidance of blueEnergy technicians. The filters are then left to dry in blueEnergy's workshop where the technicians repair any faulty filters. After approximately one month the filters are delivered to the beneficiary's houses and the sand and gravel is installed in-situ by blueEnergy technicians. Following the installation the technician provides a basic training session to the entire family on the correct use of the filter. The family contributes 50 córdobas (approximately US$2) and is also provided with a plastic 20L bucket fitted with a tap and lid to collect the filtered water and a small bottle of chlorine to disinfect the water after the filtration.

The aim of this project was to investigate the treatment efficiency and social acceptance of biosand water filters installed in the RAAS, Nicaragua to assess whether the technology is appropriate for the communities of the RAAS and to identify areas for improvement in blueEnergy's biosand filter program. The objectives were to investigate whether patterns of use affect pathogen removal efficiency, assess levels of recontamination in the stored, filtered water and assess overall uptake of the technology across the city of Bluefields and the remote communities of Kahkabila and Monkey Point.

Methods

Participant selection and visits

Families in five different neighbourhoods in the city of Bluefields and in the remote communities of Kahkabila and Monkey Point were randomly selected and invited to participate in the study in late 2011. All families selected had been beneficiaries of a biosand water filter and had received training in the use of the filter along with basic hygiene training through blueEnergy's water and sanitation program between 2009 and 2012. The families were visited during the dry season (~January to May) and asked a series of questions relating to their usage of their biosand filter along with their overall satisfaction with the filter. The filters were inspected for defects and standard measurements taken (e.g. depth of sand, depth of water above sand). Water samples were then collected and analysed for thermotolerant coliforms (as an indicator of faecal contamination) using a Wagtech PotaKit portable water quality testing laboratory.

Sample collection and microbiological analysis

During each visit a bucket of water was collected from the water source that the family typically uses for their filter, using the family's own receptacle. The water was then filtered through the biosand filter and the flow rate recorded. A total of three samples were collected from each family: one from the bucket of source water; one from the outlet tube of the filter during the filtration; and one from the bucket in which the family's filtered water is stored. 100 mL of each sample was filtered through a 0.45 µm membrane filter and placed onto a growth pad saturated in membrane lauryl sulphate media in a sterile petri dish. Samples were resuscitated for 1to 4 hours prior to incubation and all samples were incubated within 6 hours of collection. After a 14 hour incubation at a temperature of 44°C, the number of thermotolerant coliform colonies was counted in each sample with results expressed as colony forming units per 100 mL (CFU/100mL). Where more than 200 colonies were present the number of colonies was deemed to be 200 due to difficulties estimating large numbers of colonies.

Calculations and data analysis

The efficiency of each biosand filter was calculated using the following equation:

$$\text{Filtration efficiency} = \frac{\text{Number of colonies}_{\text{(water source)}} - \text{Number of colonies}_{\text{(filtered water)}}}{\text{Number of colonies}_{\text{(water source)}}} \times 100$$

Where the number of coliforms in the filtered water was less than 10 CFU/100 mL, the filtration efficiency was deemed to be 100%, to avoid the influence of calculated low filtration efficiencies where the number of thermotolerant coliforms were reduced from comparatively low levels of approximately 10 – 20 CFU/100mL to less than 10 CFU/100 L. The data was compared using a student's t-test (two tailed, heteroscedastic, $\alpha = 0.05$).

Results

Use of filters

Of the 86 families that participated in the study, 64 families (75%) were actively using their filters, while 22 families (25%) no longer used their filters. In the remote community of Monkey Point, use of filters was particularly low, with only 7 out of the 14 filters remaining in use (50%). One interesting reason for not using the filter was the lack of access to a constant water source (stated by 5 families). During the dry season, the shallow wells belonging to these families had run dry and they were consequently sourcing water from a variety of sources (e.g. water vendors, neighbour's wells, communal wells etc.). They understood that the filters needed to be used with one constant water source and had therefore stopped filtering their drinking water. Other reasons for not using the filter included defective filter, too much effort, didn't see the point, prefer to buy water, matriarch travels frequently to other communities and matriarch is always working.

Of the families that were still using their filter, all indicated that they liked their filter. 29% of the families reported that their filter had allowed them to change their drinking water source to a more convenient source, such as a private well that was considered to be too contaminated to drink without treatment.

Contamination levels

Thermotolerant coliform levels in the source water ranged from 0 to 200 CFU/100mL, with a mean of 73 CFU/100mL. 21% of source water samples had extreme levels of contamination with more than 200 CFU/100mL. Monkey Point had the highest average contamination levels in the source water (136 CFU/100mL) whilst Kahkabila had the lowest (30 CFU/100mL) (average of 82 CFU/100mL in Bluefields) (Figure 1). The average contamination level in the filtered water across the project was 10 CFU/100mL; however 63% of filtered water samples had 0 CFU/100mL. A total of 84% of the filters in the study produced water that was considered safe to drink (≤10 CFU/100mL), compared to only 21% of the source water samples. Recontamination of the filtered water occurred in 66% of the storage buckets (average contamination in storage buckets 41 CFU/100mL); however 45% of the stored water samples were still considered safe to drink (≤10 CFU/100mL).

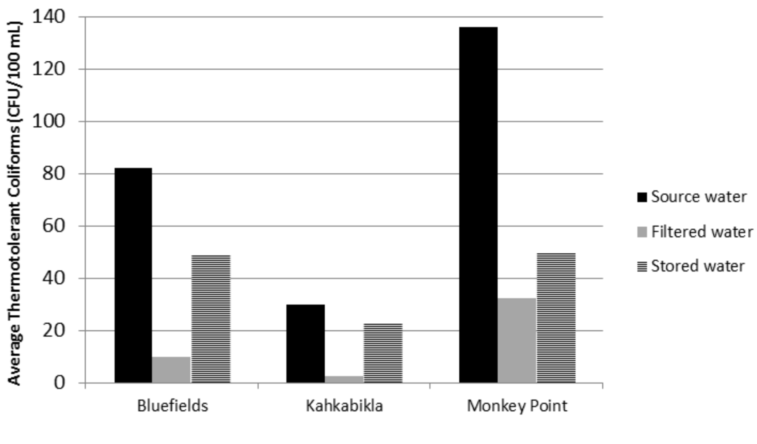

Figure 1. Average thermotolerant coliform levels across the study

Filtration efficiency

Across the study, the average filtration efficiency was 89%. There was no significant difference in the average filtration efficiency or in the level of contamination in the filtered water between families who used their filter at least daily, and families who used their filter less frequently than daily ($p = 0.3$ for both). Filtration efficiencies of 100% were still common (92%) amongst filters that were used infrequently (i.e. less than 4 times per week). The average filtration efficiency varied slightly however, depending on when the filter was last used prior to the filtration during the visit. The filters that had already been used on the same day as the visit had a slightly lower efficiency (77%) than those that had not been used since the day before (99%) ($p = 0.018$). Neither filtration efficiency nor level of contamination in the filtered water varied with the level of standing water measured above the sand prior to the filtration (p = 0.16, 0.53). Flow rates ranged from 0.08 L/min to 1.7 L/min but were not found to influence filtration efficiencies (R^2 = 0.04).

Recontamination

There was no statistical difference in the level of contamination in the stored filtered water between families that used buckets equipped with taps supplied by blueEnergy and families that used other types of buckets (e.g. uncovered buckets that do not have a tap) (p=0.46). The level of contamination in the stored filtered water was also not significantly different between families that used different buckets for collection of source water and storage of filtered water and families that used the same bucket for these activities (p=0.6). The level of recontamination in the storage bucket was also not significantly different between the families that used chlorine compared to those that didn't use chlorine in their storage bucket (p=0.7). 32% of the study participants indicated that they used chlorine to provide an extra barrier against contamination in their buckets of stored filtered water (although only 60% of this group used chlorine in the way recommended by blueEnergy: 5 drops per bucket). 22% of the participants didn't use chlorine even though they had chlorine supplied by blueEnergy in their house, while 42% did not use chlorine and didn't have any available (5% didn't know).

Discussion

The results of this study highlight the very high levels of pathogen removal achievable in the field with biosand water filters and the ability of the filters to produce water that is safe for drinking. The filters were found to be effective at removing pathogens at a range of different pathogen levels and were still able to provide excellent filtration efficiencies (frequently at 100% efficiency) with heavily contaminated source water (>200 CFU/100 mL). These results support the findings of other similar studies of biosand water filters conducted in the field (e.g. Vanderzwaag et al. 2009, Duke et al. 2006, Stauber et al. 2006, Fewster et al. 2004).

The results also indicate that the filters are a particularly robust technology in the field that do not necessarily require strict regimes of use and maintenance to ensure effective pathogen removal. This was evident by the lack of influence of frequency of use and standing water level on either the pathogen removal efficiency or the level of contamination in the filtered water. This result is contrary to the findings of other studies (e.g. Vanderzwaag et al. 2009) where these parameters had a significant influence on the filtration efficiency. This lack of correlation may have been due to other more significant factors that were not accounted for in the study, such as contamination on the filter outlet tube or may also reflect the relatively small sample size in the study. Nevertheless, the key implication of this finding is that biosand filter users who are not following the specific recommended regime of use and who do not necessarily have the correct level of sand or flow rate can still obtain clean drinking water for their families from their filters.

Recontamination of the stored, filtered water was highlighted to be a significant and widespread problem in this study. This issue has been highlighted by other studies such as Duke et al. (2006) and other unpublished work identified in CAWST (2008), however is still rarely given as much attention in the literature as filtration efficiency. In recognition of the potential for recontamination of stored, filtered water, blueEnergy incorporated the provision of a 20L plastic bucket fitted with a lid and a tap to each beneficiary in its biosand filter program in 2011. Beneficiaries are also provided with a small bottle of chlorine for disinfection and are able to obtain refills of chlorine when their bottle runs out. During training sessions both prior to the installation of the filter and at the time of installation, the importance of good levels of personal and domestic hygiene are stressed, along with the recommendation to add 5 drops of chlorine to the bucket after each filtration. The importance of the use of separate buckets for the collection of source water and storage of filtered water is also emphasized during these sessions. However, the results of this study indicate that individually, none of these factors resulted in a reduction in the level of recontamination in the stored, filtered water. This may indicate that the contamination is typically associated with the tap of the storage bucket, which may be likely in cases where children or animals have access to the filter or where the family has a generally poor level of hygiene. If this is the case, recontamination could potentially be reduced through the promotion of better cleaning of the buckets with particular attention to cleaning the taps along with further promotion of hand washing prior to touching the tap. The finding that the use of chlorine did not result in lower levels of recontamination was unexpected, and may indicate that the recommended dosage (5 drops per 20L) is inadequate.

Regardless of the exact cause of the recontamination identified in this study, the levels of recontamination strongly point to the well known importance of pairing hardware programs with strong 'software' programs such as hygiene promotion. The finding also highlights the importance of focusing on prevention of recontamination rather than solely in improvements in filtration efficiency, as small improvements in filtration efficiency made through maintaining correct regimes of use and maintenance are likely to be eclipsed by the magnitude of recontamination of the stored water if this issue is not given adequate attention.

The lower use of the filters installed in the remote community of Monkey Point highlights the difficulties associated with maintaining use of the technology in remote areas where project follow up is expensive and logistically difficult. Lower levels of uptake of the technology in Monkey Point are anecdotally associated with the transient nature of the community members who often move between Bluefields and Monkey Point. The much higher level of uptake of the technology in the remote community of Kahkabila is anecdotally associated with the fact that the commencement of the program in this community incidentally coincided with health concerns amongst the community members and the belief that the water was making them sick. It is also likely to be attributable to the significant efforts of blueEnergy staff members during the implementation of the project, where blueEnergy staff members spent considerable amounts of time in the community during the rolling out of the technology.

Conclusions and recommendations

The high levels of pathogen removal that have been measured in this study add to the body of research and field evaluations that affirm the effectiveness of the filters in the field. The robust nature of the technology, as indicated by filters still effectively removing pathogens even when the users did not adhere to the recommended regime of use or may not have the correct levels of sand or standing water is an important finding for other biosand filter projects.

Prevention of recontamination of the stored, filtered water is an important issue highlighted in this study that needs to be prioritised in future biosand filter projects. It is recommended that this is addressed through strengthening of the hygiene promotion and training programs that should be an integral component of biosand filter projects, and more frequent follow up visits with biosand filter users. It is recommended that improved designs are investigated for containers in which to store filtered water that fit the design of biosand filters that reduce the potential for recontamination.

It is also recommended that the impact of varying the water source on the pathogen removal efficiency is investigated in the future. This will be particularly important for areas with distinguishable wet and dry seasons where wells tend to run dry in the dry season, forcing families to access alternative sources of water, such as along the Caribbean Coast of Nicaragua.

Overall, this study has found that biosand filters are a well-received, appropriate technology in the RAAS, Nicaragua whose use has resulted in improved drinking water quality for hundreds of families. The results of this study will drive improvements in the implementation model of blueEnergy's biosand filter program and can also be used to guide other biosand filter programs around the world.

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Note

This paper is based on work undertaken by Jayne Richards, Vladimir Pao Lagos and other members of blueEnergy's Water and Sanitation Team during 2011 and 2012. It should be noted that the participating families were visited a second time during the wet season with water samples collected and analysed again, however the data from these follow-up visits was not included in this paper.

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