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Long-Term Sustainability of Using Hemodialyzers to Inexpensively Provide Pathogen-Free Water to Remote Villages Lacking Electricity

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Abstract: The provision of clean water to remote communities is a major goal of both the World Health Organization and the United Nations. We report on the long-term sustainability of filter-sterilizing polluted water in remote villages in Ghana that lack electricity. Contaminated water pumped several times a week via a gasoline pump into a 1000 L elevated tank is filtered through polysulfone hemodialyzers on demand. The 3 nm fiber pore size rejects all bacteria, parasites, and viruses. Villagers flush organic matter from the dialyzers thrice daily to maintain a flow of up to 250 L/h. Having previously reported a 73% reduction in diarrheal episodes, we now address system sustainability. After passing through the hemodialyzer filters, a fecally polluted water source remains consistently free of pathogens even after the system has been in place for >1 year in most villages. Filters are easily replaced when needed. Daily cost for unlimited clean water is less than USD 2.22 per village over five years. Villagers have continued to independently fill the tank and flush the system, because they appreciate the clean water and health benefits. We demonstrate that over 2–6 years this system providing pathogen-free drinking water can be maintained independently by villagers for long-term sustainability. It does not require electricity nor disinfectants to be added to the product water and is ready for far broader application in similarly remote settings.

Keywords: purified water; membrane filtration; filter longevity

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1. Introduction

The World Health Organization (WHO) recently provided a summary of drinking water concerns that are alarming, including the following: 785 million people lack even a basic drinking water service, the drinking water for at least two billion people is contaminated by feces, and half of the world's population will be water-stressed by 2025 [1]. Parasites, bacteria, and viruses may cause diarrhea. Ponds and rivers may be continually infected by coliform bacteria and pathogenic viruses. Diarrheal episodes take a particularly heavy toll on children, including missed schooling, malnutrition, hospitalizations, kidney damage from diarrheal volume depletion, and even death [2–6]. Furthermore, women often bear the burden of spending many hours per day retrieving water and caring for ill children, foregoing their own education and career opportunities. Remote African villages in particular are at grave peril for the transmission of water-borne pathogens and often lack even basic capabilities to combat the challenge. Absence of electrical or solar power in such settings typically precludes reverse osmosis procedures to cleanse the water. Flooding may contaminate water from wells or boreholes. Antiseptic agents may be added to drinking water, but this approach incurs costs and poses the risks of inadequate levels and poor palatability.

We have previously described a novel solution to water purification in areas without even basic power sources [7–9], employing hemodialyzers that have been used once previously for the treatment (blood purification) of patients with kidney failure and then reprocessed and sterilized [9]. The 3 nm pore size of the fibers within the hemodialyzers is so small that pathogens including viruses cannot pass through the device and filtered water is thus sterile. It further lowers the amount of medical waste produced by waste disposal of used dialyzers by kidney treatment centers. The water can be hand-pumped, or a small gasoline-powered pump can fill elevated tanks, permitting gravity-driven filtration through the hemodialyzers without the need for electricity or solar power.

We now revisit the efficacy of this device in Ghana and expand our reporting of the sustained duration and practicality of this approach used by our non-profit, non-governmental organization (NGO), Easy Water for Everyone (EWfE). For any water treatment system, the question of sustainability is of critical importance, therefore we focus here on factors that assure long-term successful function.

2. Methods

We report on the experience of 19 villages in Ghana that lack electricity and where water sources have been chronically contaminated with fecal bacteria. The population size in these villages ranged from 180 to 1489 villagers. The first sites were started on this system in 2015 with the most recent additions in this study in 2019. Our system is based on hemodialysis membranes that have, as outlined above, the capability to remove all pathogens, including bacteria, parasites, and viruses, and thus can produce sterile water by filtration [9]. Each of the 8 hemodialyzers contains hollow fibers of polysulfone with a pore size of 3 nanometers and a surface area of almost 2 square meters. The NUFiltration company has produced a patented device (NUF500) utilizing 8 hemodialyzers with all necessary connecting tubings. The typical set-up is shown in Figure 1.

Figure 1. The typical set-up.

The hemodialyzers had been reprocessed and sterilized after a clinical use in patients with kidney failure. The reprocessing method used is a well-established, standardized procedure by the Association of Advancement of Medical Instrumentation [10] that allow multiple use in hemodialysis patients.

This NUF500 hemodialyzer filtration system can produce sterile water at a rate of 250 L/h through on-demand gravity flow from a 3-meter elevated tank whenever the faucet is opened [7]. The tank size is 1000 L, except for 2 villages where it is 4500 L.

3. Results

To initiate a village for the Easy Water for Everyone system we found it useful to meet with village elders and explain the health benefits of this system and the need for two villagers to be trained to do a flushing procedure of the hemodialyzer filters thrice daily to maintain a high flow of clean water. Learning from neighboring villages of the major health benefits of the system greatly facilitates enthusiasm and adaptation. Showing the large color difference of the source water and the clear filtered water is also persuasive. Mothers have been the strongest advocates for the clean water because they see the immediate and dramatic reduction of diarrheal episodes among their children. They also assure the regular flushing of the hemodialyzers. If the backflushing is missed for more than one session, it becomes obvious by a slower flow of clean water at the faucet and prompts immediate corrective action. A prolonged flushing procedure is then needed to remove accumulated debris from the hollow fiber lumens and restore the high flow rate.

Our EWfE staff fills the elevated water tank using a portable gasoline-driven pump. The frequency of these fillings is determined by the water usage, which depends largely on the size of the population. Some villagers asked to do the pumping of the water independently, and gradually we have supplied all villages with their own pumps. This gasoline-driven pump and tubing has a typical cost of USD 300. After receiving on-site training, every village has independently filled the water tank since early 2020. This autonomous practice has proven successful for over one year at all villages. Most recent data show that the tank is typically filled three times a week, and even more often in four villages which are more populated.

Two disposable prefilters are installed at the bottom of the tank to clear larger organic matter and sediment before they reach the hemodialyzers. These prefilters are replaced as needed once a month by trained villagers. They also clean the water tank once a month.

The original hemodialyzer filters have been in place for more than one year in 78% of villages. In fact, among the villages with more than a three-year follow-up, half were still functioning beyond three years. The cost of eight replacement reprocessed filters, when needed, is USD 64.

The two main reasons that necessitated the occasional replacement of the hemodialyzers were uncontrolled growth of algae or neglected flushing of the system. The growth of algae has been avoided through the prevention of sunlight exposure of the water (using opaque black tanks and tubing). We have recently instituted a policy to routinely replace the eight hemodialyzers after 2 years as a preventive measure, even when they function well. The replacement is a simple procedure done by the staff of EWfE.

The cost of setting up the hemodialyzer filtration system for new villages has increased (perhaps related to COVID-19) since our detailed assessment in 2020 [7], but remains quite low. The initial cost is now about USD 3100 which includes USD 1100 for the filtration device (NUF500). The maintenance cost for 5 years is estimated at USD 960. Thus, for the first 5 years the total cost is about USD 4060, yielding an averaged daily cost per village of USD 2.22. These numbers apply for villages with up to 1500 population. The average daily cost after the fifth year, beyond the up-front cost of purchase and installation of tanks and pumps, is expected to be substantially lower, about USD 0.60.

Since no disinfectants are needed with our filter sterilization, there is no need to monitor disinfectant levels in the drinking water. Consequently, there is no risk that unpalatable disinfectants will discourage the use of the treated water. Thus, our system's simplicity and the purity of the water are major advantages. The long-term sustainability of the hemodialyzer filtration system is summarized in Table 1. Note that none of the villages have switched to an alternative water treatment system.

Table 1. Factors supporting long-term sustainability.

Since this system reduced diarrhea incidence	73%
The village elders and mothers are strongly supportive	100%
Trained villagers flush the hemodialyzer system daily	100%
Villages now using a gasoline-powered pump to fill the water tank regularly	100%
Villagers replacing prefilters regularly	100%
Low rate of hemodialyzer filter replacement in 1st year	22%
Zero villages have switched to an alternate clean water source	0%
Low long-term daily cost per village	First 5 years averaged USD 2.22
	Subsequent years USD 0.60

4. Discussion

The immediate and dramatic reduction in diarrhea motivates villagers to consistently maintain the system. The profound positive influence of mothers can not be overestimated. Another sign of the strong commitment of villagers is their eagerness to receive their own gasoline-driven pumps to regularly fill the water tanks without the need for regular visits from EWfE staff. All this points strongly to sustainability for many more years than what was observed over the last 2 to 6 years. The practice of flushing the filters on a three times daily schedule by trained villagers has been quite remarkable. An important reason for this lasting success may be the almost immediate feedback that is provided at the faucet, where the flow rate drops noticeably within less than 24 h, if the flushing of the filters was missed. On such occasions, effective remedial action can be taken immediately.

The longevity of the original sets of hemodialyzer filters beyond one year in most villages is a further indication of the regular maintenance by the villagers. When necessary, replacement sets of hemodialyzers are available at the EWfE office in Accra, Ghana and are easily installed.

Procuring reprocessed filters following a single use in patients with kidney failure reduces the cost of hemodialyzers. This reprocessing procedure is routine in many dialysis facilities so that the hemodialyzer can be used repeatedly for the same patient with kidney failure [11,12]. The safety of reprocessing hemodialyzers for water purification is assured by the relevant methods used for hemodialysis patients whose entire blood volume is repeatedly exposed to reprocessed hemodialyzers during a hemodialysis session. An additional benefit of this approach is that reusing hemodialyzers helps reduce the eco-burden of discarding hemodialyzers by medical centers.

Alternative methods for providing safe drinking water are described elsewhere [5,13]. Most require the addition of disinfectants and the monitoring of disinfectant levels to assure effectiveness. Common halogen disinfectants are known to impart an unpleasant taste to the water [14]. Further, if disinfectant levels become too low the water is unsafe. Many methods such as reverse osmosis [7] require electricity or solar power, which are generally unaffordable in the remote villages we serve.

Distribution of reverse osmosis water in sachets has been reported as successful in Ghana [15], but it may not be practicable due to the remoteness or small size of villages and cost.

Digging very deep wells might be a feasible solution particularly for larger villages [1]. However, this approach may be limited due to the relatively high cost and potentially due to the inaccessibility of heavy drilling equipment, e.g., at estuary island villages in the Volta River area of Ghana where about half the currently served villages are located.

Sanitation and hygiene also deserve attention [16]. In a recent survey we found that open defecation is practiced in over 90% of the households that we serve and even deep wells could become contaminated. While we agree with the W.A.S.H. (Water, Sanitation and Hygiene) program of the United Nations and WHO [17], we learned from our earlier study that providing clean drinking water alone has shown a very large reduction in the incidence of diarrhea [8]. Therefore, we consider provision of clean water as a first line of action and hope to expand our program to more villages in great need of clean water. Hygiene and sanitation are expected to provide additional health benefits [4,18]. We are in the process of initiating handwashing stations in all villages that we serve with our EWfE system.

5. Conclusions

Self-sufficiency in managing the provision of clean water within remote villages has resulted in multi-year sustainability of our hemodialyzer water filtration system. The simplicity of this gravity-driven system and the strong motivation based on the observed large health benefits has motivated villagers to be self-sufficient. Given the widespread need for clean water in many countries, particularly in rural areas without electricity, the expansion of this simple, highly effective, and low-cost program with proven sustainability is feasible. However, to date, funding through individual charitable giving has been limited. A far greater expansion could be accomplished with major sponsorship, be it private, corporate, NGO, and/or governmental.

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