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Comparing the effectiveness of five low-cost home water treatment devices for *Cryptosporidium*, *Giardia* and somatic coliphages removal from water sources

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ABSTRACT

This study compared the effectiveness and sustainability of five selected cost-effective home water treatment systems in removing *Cryptosporidium* and *Giardia* spp. from water sources. These systems included: silver impregnated porous pot (SIPP), biosand filter combined with zeolite (BSF-Z), biosand filter without zeolite (BSF-S), bucket filter (BF) and ceramic candle filter (CCF). The USEPA Methods 1623 were used for the isolation and the detection of the protozoan parasites. The flow rates of the devices ranged between 0.05 and 160.5 L/h. The average turbidity of the environmental intake water samples ranged between 1.47 and 42.93 NTU before filtration and between 0.05 and 14.49 NTU after filtration. The performance of the SIPP in removing the parasites (98–100% of both oocysts and cysts from synthetic water; 96–99.6% oocysts and 96.6–99.8% cysts from the environmental water sources) and in removing viral indicator (97.7–100%) was found to be significantly higher ($p < 0.05$) compared to other filters. In spite of its low flow rate, the SIPP filter consistently produced drinking water that complied with the limits set by the South African National Standards 241 in terms of turbidity and somatic coliphages.

Keywords: Home water treatment systems; Filtration; Effectiveness; *Cryptosporidium*; *Giardia;* Somatic coliphages

1. Introduction

An increase in the global human population has resulted in a corresponding growth in safe drinking water demand. To maintain and sustain life, there is a need for the provision of safe drinking water. However, current figures indicate that about 1/7th (1 billion) of the world population do not have access to improved drinking water supplies, mainly in developing countries [1]. This condition forces communities, especially those living in rural areas, to consume any available water source from rivers, dams or ponds without prior treatment.

According to epidemiological studies, the consumption of contaminated drinking water has been associated with waterborne outbreaks of diseases such as gastroenteritis, hepatitis A, hepatitis E, etc. which are of parasitic and viral origin. Waterborne pathogens

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contribute to an estimated 4 billion cases and 2.5 million deaths from diarrheal diseases each year [2]. Progress in the detection of viruses and protozoan parasites from water has placed water quality analysis in a new perspective [3]. Enteric viruses as well as protozoan parasitic cysts and oocysts have been found to be more resistant to certain water purification processes than bacterial indicators. The presence of *Cryptosporidium* and *Giardia* species in water, even in very low numbers, poses a high risk to the consumer [4]. These protozoa have been reported to infect distal and proximal regions of the small intestine, occupying epicellular and extracellular niches, respectively, which affect host-parasite interactions, pathophysiology and disease mechanisms [5,6].

This study consequently aimed at comparing the effectiveness and sustainability of five selected home water treatment systems (HWTS) and devices in the removal of protozoan parasites (*Cryptosporidium* and *Giardia*) and viral indicator (somatic coliphages) from surface and ground water sources. The main objectives were to firstly survey locally and internationally available HWTS and devices potentially suitable for the treatment of water on a household basis, secondly to compile a short list of the HWTS and devices which could conceivably be applied under the conditions of South Africa and prioritise them in terms of feasibility of use and suitability of application to various source water types and quality based on evaluation in literature and thirdly, to compare their efficiency in removing pathogenic microbes (protozoan parasites and somatic coliphages) as well as their compliance with South African National Standards—SANS 241.

2. Materials and methods

2.1. Selection criteria of home water treatment units

Through an extensive literature review, the selection of the appropriate HWTS which might conceivably be applied under the conditions of South Africa was carried out. The devices were selected according to their robustness, ease of construction, ease of operation, accessibility (locally) and cost effectiveness. Table 1 summarises the criteria for the selection and evaluation of HWTS/devices.

2.2. Design and construction of the selected HWT units

2.2.1. Cost of the materials used for the construction of HWT units

Based on the survey, five HWT devices were considered for the purpose of this study. The biosand filter with zeolite (BSF-Z), the standard biosand filter (BSF-S) and the bucket filter (BF) were constructed at the Tshwane University of Technology (TUT) workshop, Pretoria, South Africa, and some modifications were made according to the designs in the literature [7]. The silver impregnated porous pot (SIPP) is a product of the TUT Water Research Group while the "Just Water" ceramic candle filter (CCF) was donated by Headstream Water Holdings SA (Pty) (Ltd) (Reg No. 2008/01 5564/07).

The cost of each material was important for rural communities, to reduce their dependence on outside sources. Briefly, the materials consisted of 25 L plastic buckets (R25.58 each), a spigot (R49.99 for each), 1 m clear plastic tubing (R24.99), insert elbows (R3.79 each), a socket (R 11.49 for each), thread tape (R6.49 for each), foam and filter floss (R 6.00), 40 kg fine sand (R28.00), 40 kg gravel (R30.24), 40 kg coarse sand (R34.82) and 50 kg zeolites (R155.35). It was observed that the clear tubing and the thread tape could be used to construct 2 filters, fine sand 20 filters, gravel and coarse sand 40 filters and zeolites 5 filters. The total manufacturing cost price of a SIPP filter ranges between ZAR 150 and ZAR 200. It was noted that the SIPP filter was placed in a receptacle (10 L bucket costing ZAR 14.99) and the receptacle was put on top of a 25 L bucket (ZAR 25.58) fitted with a spigot (ZAR 49.99). The total cost of the housing and collection system was ZAR 90.56. The estimated costs of the filter units are illustrated in Table 2.

2.2.2. Preparation of buckets used for sand filters

The size of the filters was designed in a way that each could be located inside the house for the user's convenience as regards use and maintenance. For this purpose, the filters were scaled-down to a 25 L bucket. A 25 L plastic bucket of 41 cm height was used for the construction of BSF-S, BSF-Z and BF (Fig. 1). As indicated in Fig. 1, holes were drilled from the bottom of the top bucket through the lid of the bottom bucket. A 2 mm circular saw was used to open a hole in the middle of the bottom bucket that was to be packed with the filter media. Thread tape was wound round the tap which was then placed in the drilled hole.

Two elbows were used to connect the tap to the pipe that moved parallel to the edge of the bucket. This pipe was then connected to the other pipe that lies parallel to the bottom of the bucket. A 25 L plastic bucket of 41 cm height was used for the construction of each of the three filters: BF, BSF-S and BSF-Z. To prevent any external microbial contamination, the buckets were thoroughly washed with distilled water

Table 1
Selection criteria for HWTS and criteria for evaluation

Selection Criteria—to choose devices to evaluate in the lab/field	Evaluation Criteria—characteristics to be tested during lab/field work
1. Can members of rural communities afford to obtain the unit? Construction and operating cost must not exceed earnings	1. Cost (capital/running)
2. Representative of a number of similar systems	2. Final water quality must comply with SANS 241
3. Systems already extensively evaluated	3. Turbidity of treated water must comply with SANS 241, <1NTU
4. Pressure requirement, maximum two metres	4. Ease of operation
5. Power requirement does not exceed equitable share	5. Storage ability and ability to deliver enough water
6. Robustness—durability of filter	6. Robustness (test)
7. Safety (DWAF Regulations for new systems)	7. Safety—ensure that the water supply system is sustainable, well managed and minimises the health impacts on the consumer
8. Minimum required volume for basic human needs 25 L/p/d, for drinking, 1.8 L /p/d	8. Social acceptance
9. Ease of construction	9. Extensive knowledge not required by user in rural community

Table 2
Cost for the construction of each of the selected HWT units

Filters	Rands (ZAR)	Dollars (USD)
BSF-S	131.85	16
BSF-Z	164.23	20
BF	140.09	17
CCF	101.15	13
SIPP	290.56	36

and sterilised under a UV light laminar flow for 24 h before use. The sands were washed thoroughly using tap water and rinsed several times with deionised water before packing them into the bucket.

BSF-S—This standard biological sand filter is constituted of three layers of various types of sand: the first layer from the bottom consisted of 2.5 cm gravel (particle size: 5 mm), followed by 1 cm of coarse sand (particle size: 0.95 mm) and a 15 cm layer of fine sand (particle size: 0.15 mm). The filter was constructed according to the guidelines of [7]. Fig. 2 illustrates the standard biosand filter without zeolite (BSF-S).

BSF-Z—This filter was constructed according to the guidelines given in the literature which was obtained from the Centre for Affordable Water and Sanitation Technology [7]. In addition to the size of the filter that was scaled down to 41 cm height and 32 cm width, the BSF-Z contained an extra layer of clinoptilolite zeolite that served as filter media. It has been reported that natural zeolites possess antimicrobial properties in soil and water which can also inhibit a number of viable microorganisms in water [8]. This medium was thus added to this filter to determine whether it could enhance the performance of a biosand filter. This modification to a household biosand filter is unique to this study and has not been reported

Fig. 1. Materials used in the manufacturing of the HWTS.

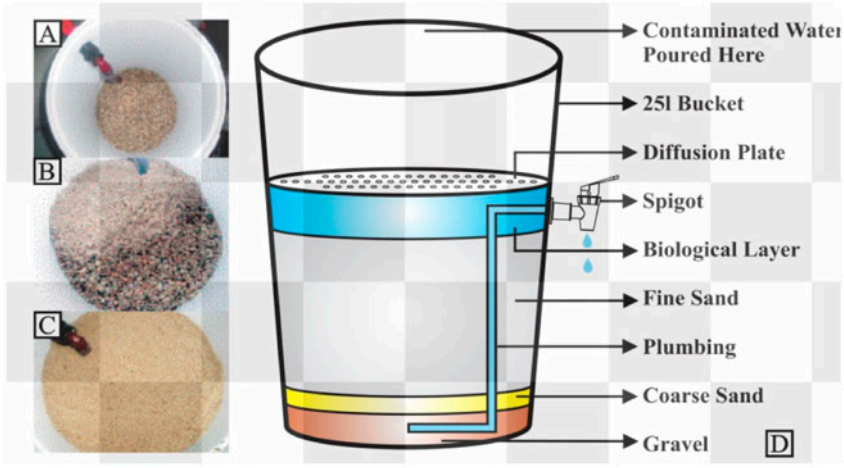

Fig. 2. Three layers within the BSF-S: A—plumbing, gravel and coarse sand layers, B—fine sand layer and C—fine sand layer with supports for the diffusion plate D—diagram of the BSF-S showing the filter content.

elsewhere. The construction of this BSF-Z is described in Fig. 3. From the bottom of the bucket, the filter consisted of a 3 cm layer of gravel (particle size: 5–7 mm), followed by a 2 cm layer of coarse sand (particle size: 0.95 mm), 7 cm of crushed zeolite particle (size: 3 mm) and a 5 cm layer of fine sand particle (size: 0.15 mm). The filter also consists of a biological layer which was 5 cm above the top layer of the sand. A diffusion plate was made on top of the biological layer in order to protect and reduce any disturbance to the top layer of the sand when water is being poured into the filter.The diffusion plate has also been reported to entrap suspended particles [9].

BF—Two 25 L buckets were used for the construction of the BF. Holes were drilled at the bottom of one of them. As illustrated in Fig. 4, the top bucket packed with the sand media was placed above the second bucket where the filtered water drained. The top one was filled with a 5 cm layer of gravel (particle size: 5–7 mm), followed by a 20 cm layer of fine sand (particle size: 0.3 mm). The PVC glue was used to make sure that the lid remained intact with the bottom of the top bucket. The tap was placed in the bottom bucket, which served as the collection vessel (Fig. 4).

CCF—This filter also consists of two 25 L buckets: one for filtration and the other for the collection of

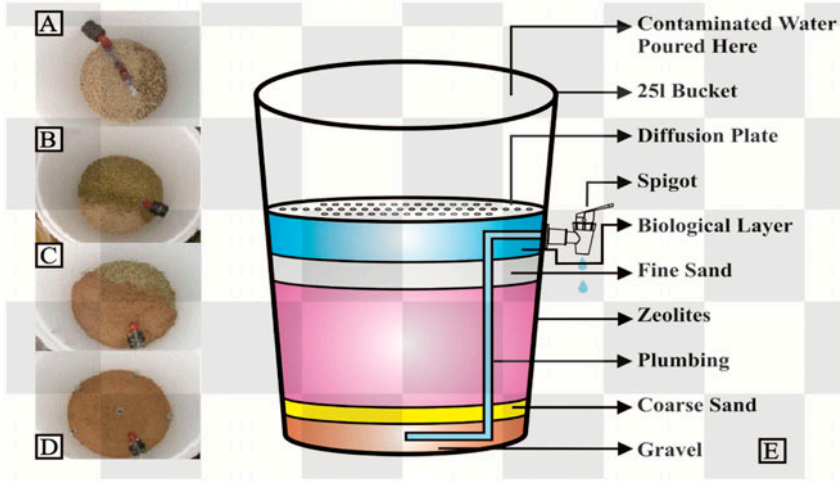

Fig. 3. Four layers within the BSF-Z: A—plumbing, gravel and coarse sand layers, B—coarse sand layer and zeolite layer, C—fine sand layer and D—fine sand layer with supports for the diffusion plate. E—diagram of the BSF-Z showing the filter content.

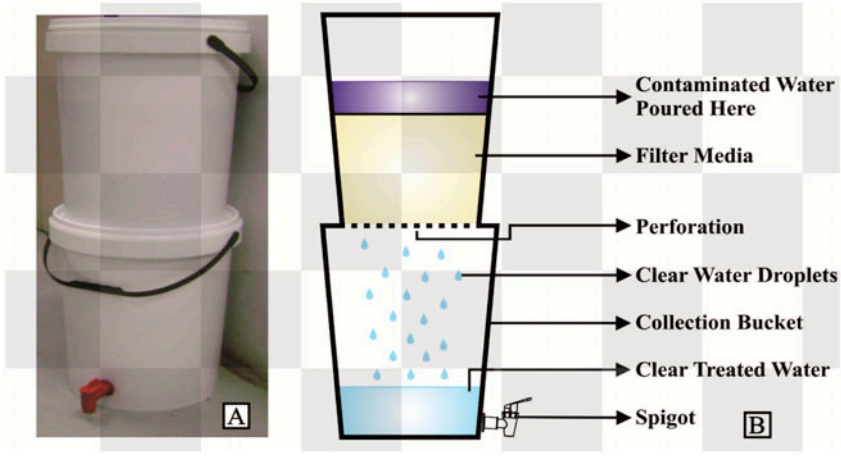

Fig. 4. Diagram of the BF showing the two layers within the system: (a) gravel and fine sand layers, (b) setup of the finished BF.

filtered water. The two were stacked on top of each other. A hole was drilled from the base of the top bucket through the lid of the bottom one. The upper bucket consists of a domed-shaped candle which was fitted and screwed to the lid of the bottom bucket. There was a cloth over the ceramic candle which helped to trap larger particles and reduce contamination. The spigot was placed in the bottom bucket where water is collected for consumption after filtration. An illustration of the CCF is provided in Fig. 5.

SIPP—The SIPP filter was manufactured by the Tshwane University of Technology under a Water Research Commission project (K8/810). It was made from a mixture of sawdust and brownish clay, also impregnated with silver nitrate (23.5 g) and fired in order to fix the silver to the pot to make it last longer. This filter is different from other silver impregnated colloidal pots that are coated with silver after firing the clay pot [10]. Fig. 6 illustrates the diagram of the SIPP.

2.3. Water sample collection and preparation

2.3.1. Preparation of synthetic water samples

The seeds for *Cryptosporidium parvum* and *Giardia lamblia* were obtained from the Wisconsin State Laboratory of Hygiene (USA). For each test water sample, 100 oocysts and 100 cysts were spiked into 20 L sterile deionised saline water (8.5% NaCl). The spiked water samples were thoroughly mixed prior to passing through each filter. Three trials were used for each type of filter systems.

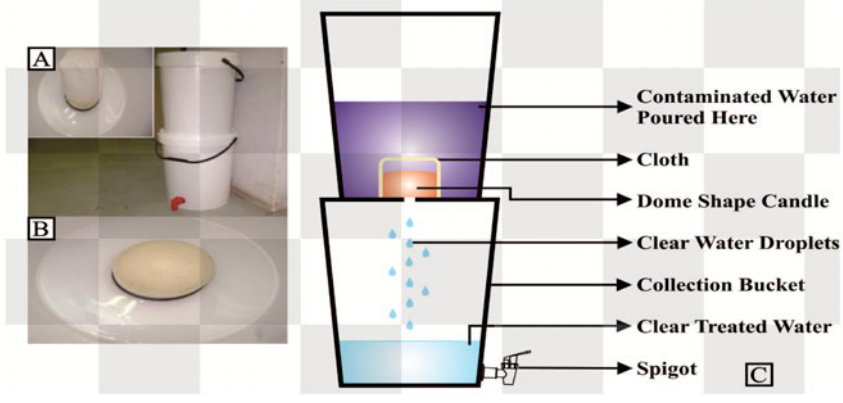

Fig. 5. Illustration of the CCF; A—the CCF and the setup, B—schematic diagram of the CCF.

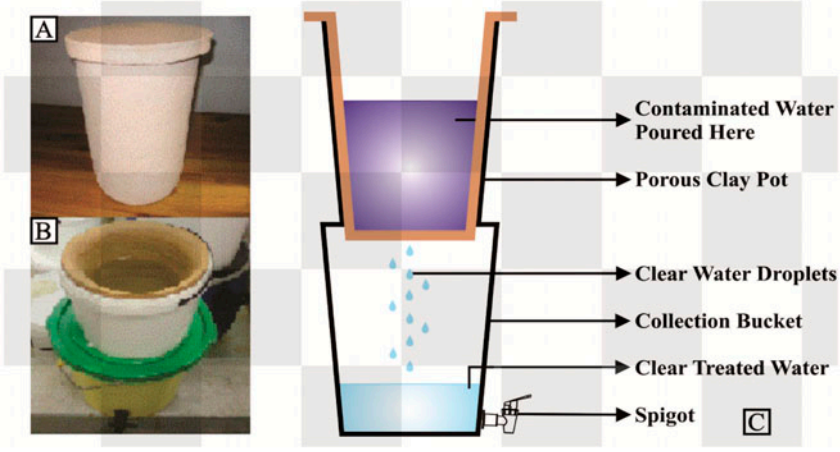

Fig. 6. The SIPP and the set up (a), schematic diagram of the SIPP (b).

2.3.2. Collection and preparation of environmental samples

Environmental water samples were collected six times from each of the four different sources between 27 September 2010 and 18 March 2011. Surface water samples of low turbidity (SWL) were obtained from the Apies River in Hermanstad (Pretoria, Gauteng Province), while those of surface water with high turbidity (SWH) were collected from Hartbeespoort Dam (North West Province). Ground water samples with low (GWL) and high (GWH) turbidity were collected from boreholes situated in different areas in Delmas (Mpumalanga Province) and Wallmannsthal (Mpumalanga Province), respectively.The collection of water samples was carried out using 20 L sterile plastic containers which were immediately transported to the laboratory for analysis. During the study period, the USEPA 1623 method [11] was used to determine the initial concentrations of *Cryptosporidium* and *Giardia* spp. from the environmental water sources. In cases where target organisms were not detected in environmental water samples, 100 oocysts and 100 cysts were spiked into test water sources. The spiked water samples were shaken vigorously several times before being passed through the filtering devices.

2.4. Evaluation of the performance of the devices

2.4.1. Filtration process

The filters were evaluated for their efficiency to remove target organisms from synthetic and environmental water sources. Filtration was carried out by taking into consideration that rural communities may use any available water source that is accessible to them during seasonal changes. This process was performed in the laboratory (Tshwane University of Technology) in a manner that mimics the situation that would be taking place in homes in rural areas. Test water sources were filtered through each device upon arrival in the laboratory as follows: 5 L for SIPP and 20 L for each of the remaining filters. Different volumes of filtrates were collected at 1 h intervals over the 3 h period of filtration with the assumption that sufficient purified water would have been produced over this period of time for drinking and cooking. This also allowed the researchers to establish whether significant differences in the reduction of microbial contaminants can be found at different interval times and to make the necessary recommendations in terms of safe drinking water. Total volumes of all water types filtered amounted to 305 and 1,220 L for the SIPP and the other four devices, respectively. The collected samples were analysed in triplicate to determine the water quality after filtration. The concentrations of target parameters were determined before and after passing the contaminated water samples through the filter systems. The quality of the water produced in terms of turbidity level and target organism concentrations was compared to the South African Drinking Water Guidelines [12].

2.4.2. Flow rate testing

Source water samples were filtered through each device as follows: 5 L per day for SIPP and 20 L per day for each of the remaining HWT units. Different volumes of filtrates were collected at one-hour intervals over the three-hour period of filtration, with the assumption that enough purified water would have

been produced in this period for drinking and cooking. For this study, the flow rate was measured only with environmental samples, by recording the volume of filtered water collected every one hour for the SIPP, CCF and BSF-S during the filtration process, which was done over three hours. For the BSF-Z filter, the flow rate was determined by recording the volume of filtered water that was collected in 1 min immediately after the water had been poured into the filter. The flow rate (BF) was then determined by measuring the time (minutes) it took to completely filter 20 L of water. The flow rates (L/min) were converted to L/h.

2.4.3. Efficiency of HWTS in turbidity reduction

The initial turbidity level of the environmental water samples was recorded immediately upon arrival at the Tshwane University of Technology Water Research Group Laboratory. The turbidity level of the intake water sources and of the treated water samples was determined using a turbidity meter (EUTECH instruments—TN 100). The percentage for the turbidity reduction achieved by each of the filter devices was calculated using the equation below.

$$\%\ \text{turbidity reduction} = \frac{(\text{turbidity}_{\text{unfiltered}} - \text{turbidity}_{\text{filtered}})}{(\text{turbidity}_{\text{unfiltered}})} \times 100\% \quad (1)$$

2.4.4. Determination of silver nitrate elution by SIPP

The present part of the study is a continuous investigation into the performance of SIPP in removing pathogenic organisms from contaminated water sources. The preliminary experimental studies by Momba and co-workers [13] indicated that the silver leached from the SIPP filter was at concentrations ranging between 0.5 and 0.6 mg/L, higher than the World Health Organization (WHO) recommendation of 0.1 mg/L [14]. The Ag elution was the greatest in the early stages (within the first 5 L) but appeared to begin to stabilize after filtering 10 L. For the present study, the SIPP filter was soaked in 20 L deionised water overnight, prior to use; thereafter, the concentration of the silver in the filtered water was determined after filtering a total volume of 305 L. This was performed at one-hour intervals over a three-hour period. The first, second and third filter runs were performed with deionised water, groundwater and surface water, respectively. The Spectro Acros ICP spectrometer (Spectro, RSA) was used to detect and determine the concentration of silver in each water sample.

2.4.5. Efficiency of HWTS in removing Cryptosporidium *and* Giardia *spp.*

During the study period, no (oo)cysts were found in surface water and groundwater sources. Synthetic and environmental water samples spiked with (oo) cysts were thoroughly mixed and passed through each filter system. Water samples collected after filtration process were filtered through the Envirochek membrane capsule filter (1.0 μm pore size, PALL Corporation, Michigan, USA). The membrane capsule filters were scraped and washed using 50 mL 0.1% Tween 80 followed by centrifugation at 2,000 × *g* to pellet the (oo)cysts. The supernatants were aspirated to 10 mL above the pellet according to the US EPA 1623 method [11]. The cysts and oocysts were captured from the remaining 10 mL of the supernatant using Dynalbead anti-*Giardia* and anti-*Cryptosporidium* immunomagnetic antibodies (DEHTEQ, RSA). A 50 μL aliquot of the purified suspension containing the captured oocysts was air-dried on a well-slide and stained with anti-*G. lamblia* and anti-*C. parvum* monoclonal antibodies conjugated to fluorescein isothiocyanate (FITC) (Aqua-Glo G/C Kit, Invitrogen, USA). The slides were examined at 1,000 × magnification using an Axio Carl Zeiss epifluorescence microscope (Carl Ziess, RSA). *Giardia* cysts (~6-μm) were identified based on their size, shape and the pattern and intensity of immunofluorescent assay staining (bright green fluorescence of the cyst wall). *Cryptosporidium* oocysts (~4-μm) were identified based on their size, shape and the presence of a suture on the oocyst wall at 1,000 × magnification. The number of (oo)cysts was counted in duplicate for each sample according to the US EPA 1623 method [11]. The percentage removal of protozoan parasites was calculated according to Brozel and Cloete [15] using the following equation:

$$\text{The Kill}\% = 100 - \frac{\text{survivor count}}{\text{initial count}} \times 100\% \quad (2)$$

2.4.6. Efficiency of HWTS in removing somatic coliphages

The detection of somatic coliphages in synthetic and environmental water samples was performed using internationally accepted techniques and principles [16]. Briefly, the enumeration of somatic coliphages was performed on double-agar-layer plaque assay using the *Escherichia coli* strain C (ATCC 700078) nalidixic acid-resistant mutant WG5. The preparation of the media and the inoculum cultures was carried out as described elsewhere [16,17]. For each water sample,

the analysis was performed in triplicate. The removal efficiency of each filter was assessed by comparing the concentrations of the target organism before and after treatment using the equation mentioned above.

2.5. Statistical analysis

The statistical software package used to analyse the data is Stata V10 (Tshwane University of Technology). Data obtained after treatment were subjected to one-way analysis of variance (ANOVA) to compare more than two groups. Comparisons were made between the treatment means of each device per water source to determine whether there were significant differences between treatments. Correlations between the protozoan parasite counts and turbidity values were also determined using the Pearson correlation index at a 95 % confidence interval.

3. Results

All materials used in the manufacturing process of the five selected devices and systems are readily available in South Africa, inexpensive and can be affordable for rural communities. The filter media mainly consisted of natural resources (gravel, sand, clinoptilolite zeolite and clay) that may also be found in the environment of rural communities.

3.1. Flow rate and turbidity reduction

The flow rates of the filter systems during the sequential filtration of various water sources ranged between 0.81 and 6.84 L/h for BSF-S, between 1.74 and 19.2 L/h for BSF–Z, between 106.4 and 160.5 L/h for BF and between 1 and 4.2 L/h for CCF (Fig. 7). The SIPP system had flow rates ranging from 0.05 to 2.49 L/h. An increase in flow rates of the filters were noticed when filters were refilled with water, and thereafter a gradual decrease in flow rates occurred when the level of water in filters decreased. This could be due to the hydrostatic pressure that took place at the initial stage when water was being poured into the filters. The BF recorded flow rates ranging between 106.5 and 160.4 L/h with (SWL), 124.6 and 159.3 L/h with (SWH), 106.5 and 137.9 L/h with (GWL) and 127.2 and 142.9 L/h with (GWH), respectively. The BF flow rate was too fast compared with the flow rate of other filter systems. This flow rate was then determined by measuring the time (minutes) it took to completely filter 20 L of water. The flow rates (L/min) were converted to L/h.

The initial turbidity of source water samples was considered as one of the important factors in evaluating the performance of the selected HWTS devices. Table 3 summarises the performance of each filter in turbidity reduction. The turbidity of unfiltered water ranged between 2.56 and 26.63 NTU for SWL and between 16.4 and 42.93 NTU for SWH. The intake groundwater sources had turbidity levels ranging between 1.47 and 3.45 NTU for GWL and between 2.89 and 14.4 NTU for GWH. In general, each HWTS was able to reduce the level of turbidity from intake water sources. After filtration, an average turbidity values ranging from 0.08 to 5.75 NTU, 0.44 to 13.2 NTU, 0.08 to 5.75 NTU, 0.47 to 14.49 NTU and 0.08 to 5.34 NTU corresponding to 32–98%, 12–97%, 40–98%, 3–95%, 59%—99% turbidity removal efficiency were obtained for BSF-Z, BSF-S, CCF, BF and SIPP, respectively.

During the sequential filtration of various water sources, the highest turbidity removal efficiency (99%) was noted in SIPP when compared to other filters (HWTS). In addition, SIPP was found to be the only HWTS that continuously produced drinking water with turbidity levels complying with the allowable limit of <5 NTU. However, BSF-Z achieved the turbidity reduction of 98% after filtering a total volume of water up to 840 L. This turbidity reduction was noted after the filtration of SWL. The lowest turbidity reduction of 32% was observed during the second hour of filter run after reaching a total volume of 920 L of raw water during the filtration of GWL through the device. For BSF-S, the highest turbidity removal efficiency (97%) was achieved during the third hour after filtering 20 L SWL, to make up a total volume of 820 L water that had passed through the filter. The lowest reduction (12%) was obtained in the first hour after filtering 20 L of GWL to make up the total volume to 900 L. Compared to BSF-S, the highest turbidity removal for CCF (98%) was obtained during the second hour after adding through filter 20 L of SWH to make up a total volume of 1,120 L. Furthermore, the turbidity reduction of 95% was obtained by BF within the first hour of filtering 20 L of SWL to make up a total volume of 820 L water that passed through the device. It should be mentioned that the lowest turbidity removal efficiency of the HWTS were observed when filtering groundwater (GWL and GWH), with BF taking the lead (Table 3).

3.2. Silver nitrate elution by SIPP

As shown in Table 4, it was observed that the intake surface water and groundwater samples exhibited silver concentrations that were within the WHO recommended limits (0.1 mg/L). The amount of silver

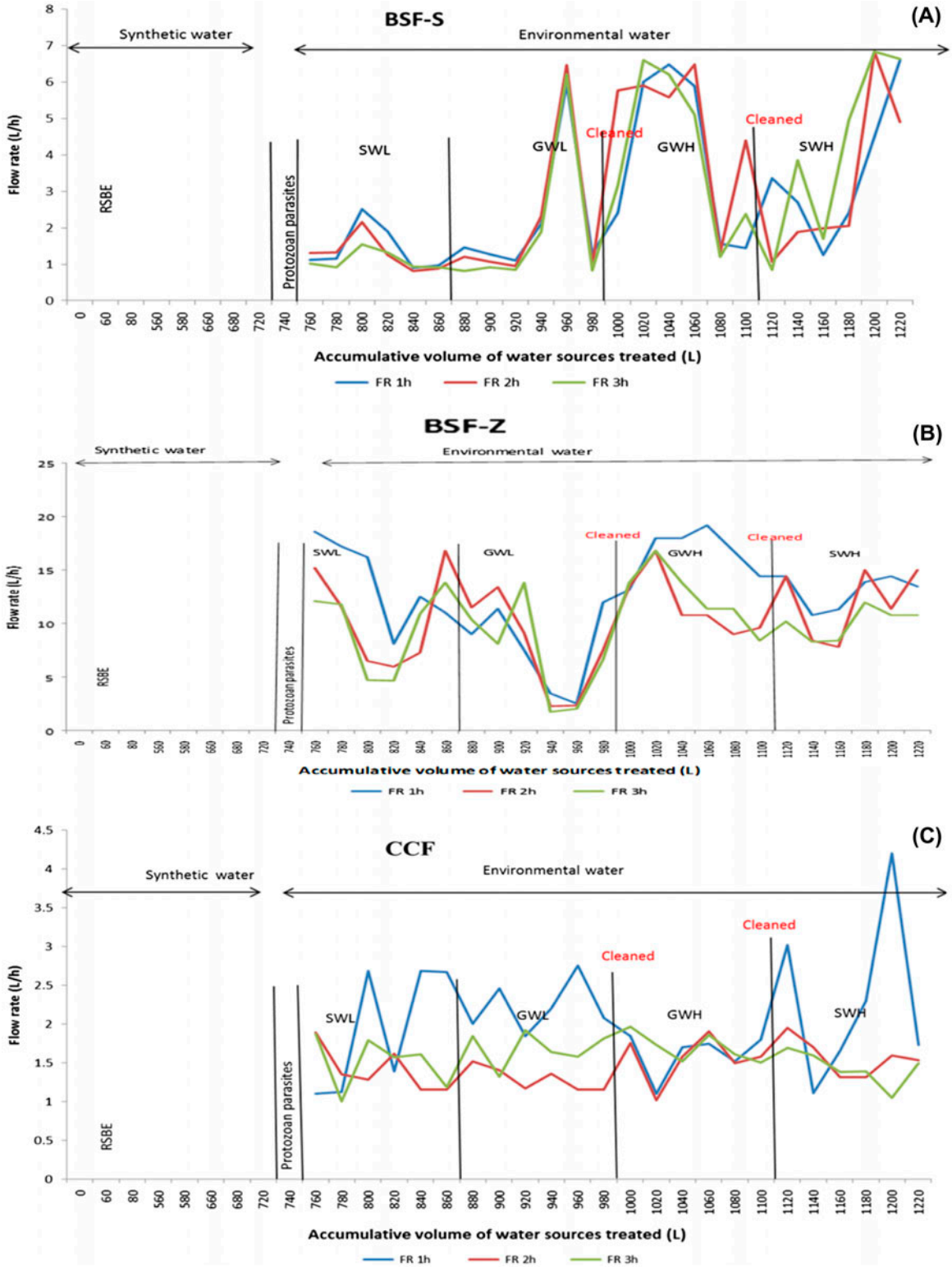

Fig. 7. (a) Flow rates of selected devices: (a) BSF-S, (b) BSF-Z and (c) CCF ([SWL—surface water of low turbidity], [SWH—surface water of high turbidity], [GWL—groundwater of low turbidity] and [GWH—groundwater of high turbidity]). (b) Flow rates of selected devices: (d) BF and (e) SIPP ([SWL—surface water of low turbidity], [SWH—surface water of high turbidity], [GWL—groundwater of low turbidity] and [GWH—groundwater of high turbidity]).

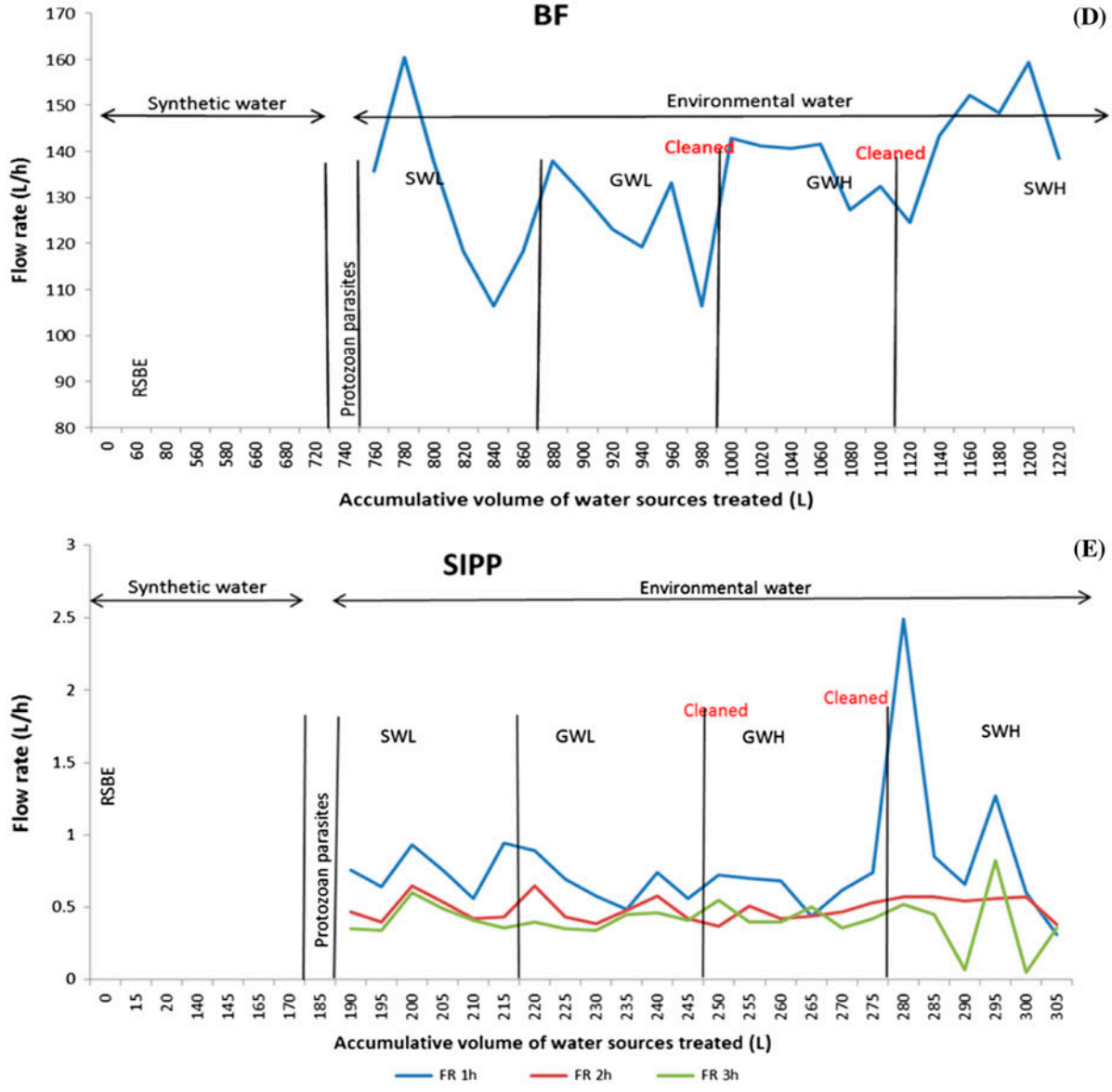

Fig. 7. (*Continued*)

leached into the water during filtration by the SIPP filter ranged between 0.98 and 0.22 mg L^{-1}. It was noted that the SIPP filter showed elevated silver concentrations in the filtrate from the first and the second run with the synthetic water sample.

3.3. Performance of filters/devices in removing target pathogens

3.3.1. Quality of test water sources before treatment

Three trials with synthetic water samples and a total of six trials with each of the environmental water samples were conducted in order to evaluate the performance of each HWTS in removing the viral indicator. The initial concentrations of somatic coliphages in water sources fluctuated during various trials and the average counts were as follows: between 10 and 130 pfu/100 mL for synthetic water, 35 and 44 pfu/100 mL for SWH, 35 and 41 pfu/100 mL for SWL, 27 and 32 pfu/100 mL for GWH and 26 and 82 pfu/100 mL for GWL. Somatic coliphage counts in intake water sources were above the limits set by the South African guidelines for drinking water, which are 0–1 pfu/100 mL [12,18]. It should be mentioned that *Cryptosporidium* oocysts and *Giardia* cysts were not

Table 3
Performance of the selected HWTS in turbidity removal (NTU) during the sequential filtration of various water sources ($n = 18$)

Water source	Before treatments	1 h after treatment	2 h after treatment	3 h after treatment	Overall average	% removal efficiency
BSF-S						
SWL	2.56–26.63	0.48–1.83	0.73–3.27	0.44–0.71	1.02 ± 0.47	42.44–97.32
SWH	16.4–42.93	1.56–13.2	1.12–11.72	4.28–11.39	6.62 ± 1.52	28.53–96.86
GWL	1.47–3.45	0.49–2.49	0.48–1.23	0.52–0.92	0.86 ± 0.24	11.66–82.52
GWH	2.89–14.4	0.73–8.1	0.69–1.22	0.53–3.19	2.43 ± 1.78	19.01–94.15
BSF-Z						
SWL	2.56–26.63	0.55–3.04	0.55–1.53	0.41–1.77	1.17 ± 0.41	43.36–97.84
SWH	16.4–42.93	1.28–2.81	1.77–3.69	1.35–5.75	2.52 ± 0.57	85.22–96.91
GWL	1.47–3.45	0.31–2.08	0.08–1.13	0.21–0.49	0.61 ± 0.26	32.44–95.24
GWH	2.89–14.4	0.56–5.59	0.38–1.19	0.42–2.82	1.94 ± 1.23	36.62–97.36
BF						
SWL	2.56–26.63	0.57–1.62	0.70–1.62	1.28–2.14	1.31 ± 0.49	21.22–95.19
SWH	16.4–42.93	2.83–8.61	3.85–8.79	5.22–14.49	7.40 ± 1.62	47.28–93.35
GWL	1.47–3.45	0.83–1.34	0.47–2.82	0.84–1.39	1.08 ± 0.12	5.40–85.90
GWH	2.89–14.4	0.57–12.19	0.76–4.14	0.67–3.16	3.63 ± 2.53	3.75–86.76
CCF						
SWL	2.56–26.63	0.67–1.67	0.52–1.47	0.32–1.87	1.10 ± 0.16	51.04–97.27
SWH	16.4–42.93	4.29–7.1	0.67–9.91	1.57–8.71	5.38 ± 1.23	68.77–98.28
GWL	1.47–3.45	0.81–1.55	0.56–1.87	0.18–1.57	0.88 ± 0.13	43.64–94.12
GWH	2.89–14.4	0.73–5.63	0.59–1.72	0.44–1.71	1.41 ± 0.66	45.85–96.01
SIPP filter						
SWL	2.56–26.63	0.39–0.76	0.54–2.32	0.76–5.34	1.40 ± 0.96	62.17–97.82
SWH	16.4–42.93	0.88–1.75	0.46–1.14	0.44–2.61	1.16 ± 0.27	89.29–99
GWL	1.47–3.45	0.35–0.63	0.05–0.76	0.20–0.68	0.47 ± 0.03	58.79–98.48
GWH	2.89–14.4	0.69–1.47	0.39–1.34	0.51–1.41	0.91 ± 0.19	68.20–94.65

Note: n = Number of sample (18).

detected in surface water and groundwater samples collected during the study period.

3.3.2. Synthetic water

Table 5 illustrates the efficiency of each filter system in removing *Cryptosporidium* oocysts and *Giardia* cysts from synthetic water sources during the study period. Overall, there was a remarkable decrease in the number of (oo)cysts from the treated synthetic water samples. Higher removal efficiency was found when removing the oocysts than cysts, and the highest performance in removing both protozoan parasites was noted with the SIPP filter system compared to other filters. Complete removal of oocysts occurred after filtering synthetic water through the SIPP devices. In contrary, the removal of somatic coliphages by selected HWTS appeared to be more efficient compared to that of protozoan parasites. All selected HWTS with exception of BSF-S showed a complete removal of the somatic coliphages (viral indicator) especially during the first trial with a decrease of time. In addition, SIPP revealed the highest removal efficiency for somatic coliphages with 100% removal throughout the experimental study.

Table 4
Silver elution by SIPP (in mg/L)

	Before treatments	1 h after treatment	2 h after treatment	3 h after treatment	Overall average
DW	NA	0.98	0.81	0.54	0.77 ± 0.22
SW	0.07	0.24	0.26	0.28	0.26 ± 0.02
GW	0.13	0.25	0.23	0.22	0.23 ± 0.01

Notes: DW: deionised water, SW: surface water, GW: groundwater.

Table 5
Protozoan and somatic coliphages removal from synthetic water sample by each filter

		Protozoan parasites			Somatic coliphages	
Filters	No of trial	Initial conc. (100 (oo)cysts/20 L)	G (% removal)	C (% Removal)	Initial conc. (pfu/mL)	% removal
SIPP	3	100	98	100	121–130	100
CCF	3	100	96	98	121–130	95–100
BSF-Z	3	100	94	96	121–130	90–100
BSF-S	3	100	93	96	121–130	90.9–95.38
BF	3	100	90	92	121–130	80–100

Notes: C = (*Cryptosporidium*); G = (*Giardia*).

3.3.3. Environmental samples

As stated above, *Cryptosporidium* oocysts and *Giardia* cysts were not detected in surface water and groundwater samples collected during the study period. Consequently, the (oo)cysts were spiked into these water sources. Table 6 illustrates the performance of each filter in removing (oo)cysts and cysts from test water sources during the six trials. In spite of the great decrease in the concentrations of (oo)cysts that was noted after filtration of both contaminated environmental water sources, the selected HWTS did not achieve a complete removal of the target protozoan parasites as stipulated in SANS 241. The effectiveness of BSF-Z in removing oocysts from surface water samples ranged between 92 and 97% and between 94 and 97 % for cysts. This filter achieved a removal efficiency rate ranging from 92 to 96% for both target protozoan parasites after the filtration of ground water samples during the six trials. For BSF-S,

Table 6
The percentage (%) removal of target pathogens from surface and ground water sources by HWTS

		Cryptosporidium (% removal)		*Giardia* (% removal)	
Filter	Total water filtered (L)	Surface water	Ground water	Surface water	Ground water
BSF-Z	1,220	92.00–96.47	92.00–95.78	94.00–96.96	92.8–95.55
BSF-S	1,220	92.00–94.73	92.00–96.00	93.00–95.91	93.87–96.00
CCF	1,220	91.76–97.75	93.87–97.97	93.87–98.30	94.00–97.77
BF	1,220	88.87–94.89	91.00–92.92	89.47–95.76	92.00–95.55
SIPP	305	96.00–99.13	96.00–98.98	98.94–99.15	97.00–98.88
Somatic coliphages					
Water sources	Before filtration (pfu/100 mL)	% removal efficiency	Before filtration (pfu/100 mL)	% removal efficiency	
BSF-S			BSF-Z		
SWL	35.0–41.0	73.2–92.7	35.0–41.0	80.5–91.4	
SWH	35.0–44.0	87.8–93.2	35.0–44.0	88.6–93.2	
GWL	26.0–82.0	84.6–96.3	26.0–82.0	88.5–100.0	
GWH	27.0–32.0	84.4–92.9	27.0–32.0	87.5–93.1	
BF			CCF		
SWL	35.0–41.0	71.8–88.6	35.0–41.0	77.1–92.7	
SWH	35.0–44.0	80.4–86.4	35.0–44.0	88.6–93.2	
GWL	26.0–82.0	77.8–96.3	26.0–82.0	88.5–100.0	
GWH	27.0–32.0	82.1–89.3	27.0–32.0	88.9–93.8	
SIPP filter					
SWL	35.0–41.0	85.7–100.0			
SWH	35.0–44.0	91.4–95.5			
GWL	26.0–82.0	92.6–100.0			
GWH	27.0–32.0	90.6–96.4			

the performance rates in removing oocysts and cysts from surface water ranged between 92 and 95%, and between 93 and 96%, respectively, whereas from groundwater (Delmas) the removal efficiency was between 92 and 96% for oocysts and between 94 and 96% for cysts during the six trials (Table 6).

The CCF reached the performance rates of 92–98 and 94–98% in removing oocysts and cysts from surface water samples, respectively. A similar performance rate in removing the two protozoan parasites (ranged between 94 and 98% during the six trials for both oocysts and cysts) was also found in the filtered ground water. Furthermore, the BF was also able to remove oocysts from surface water at various rates ranging between 89 and 95%, whereas for the cysts the ranges were between 90 and 96%. The removal efficiencies ranged between 91–93 % oocysts and 92–96% cysts were recorded when treating groundwater during the six trials using BF (Table 6). Filtration of surface water samples through SIPP resulted in treated water that contained one to four oocysts per 20 L. This was equivalent to removal efficiency rates of 96–99% oocysts during the six trials. A similar removal rate was also recorded for groundwater. However, this filter succeeded in removing *Giardia* cysts at 99% from surface water and between 97 and 99% from groundwater (Table 6).

As it can be seen in Table 6, the selected HWTS with exception to BSF-S were able to achieve a removal efficiency of 100% for somatic coliphages from environment water samples (specifically from groundwater samples with low turbidity). Despite the high performance of all selected filters, SIPP revealed another complete removal (100%) of somatic coliphages from the surface water (SWL) sources, which only occurred at the third hour during the first trial. In general, SIPP was the best performing filter and showed a removal of somatic coliphages at a rate ranged between 85.71% and 100% for SWL and between 91.43 and 95.45% for SWH. When filtering groundwater, the results indicated that the efficiency rates of SIPP ranged between 92.59 and 100% for GWL and between 90.63 and 96.43% for GWH. Regardless to the fact that BF appeared to be the worst performing filter, the results indicated that BF could remove somatic coliphages at a rate ranging between 71.8 and 88.6%, and between 80.4 and 86.4% for SWL and SWH, respectively. With groundwater sources, the performance rates ranged between 77.8 and 96.3% and between 82.1 and 89.3% for GWL and GWH, respectively. The removal efficiency of the BF gradually decreased when filtering the environmental samples. During the trials of the six surface water sources, the removal efficiency of somatic coliphages by BSF-Z ranged between 80.5 and 91.4% and between 88.6 and 93.2% for SWL and SWH, respectively. In addition, the performance rates of BSF-Z when filtering groundwater sources also ranged between 88.5 and 100% and between 87.5 and 93.1% for GWL and GWH, respectively. Complete removal of the viral indicator occurred during the third hour of the first trial when filtering up to 880L GWL. With the exception of the first trial during the filtration of the synthetic water source, the BSF-Z was not able to continuously produce drinking water that complied with the recommended limits for coliphages. Similar observation was noted when using BSF-S and CCF to filter environmental water samples.

Subsequently, a statistical multivariate analysis was performed to check the difference and relationship between the flow rate, turbidity removal and microbial removal. Statistically, the flow rates of the four devices were found to be significantly different from that of the SIPP during the treatment of all water samples ($p = 0.000$), except for the CCF which displayed a flow rate similar to SIPP when filtering SWH. The performance of SIPP in reducing turbidity from all test water samples was also found to be significantly different with those of BF and CCF ($p = 0.000$) except when filtering GWL in the CCF ($p = 0.0804$). There was no significant difference between the performance of SIPP and BSF-S in reducing turbidity during the treatment of SWL only ($p = 0.515$), while that of BSF-Z and SIPP showed no significant difference during the treatment of both surface water samples and GWL ($p > 0.05$). There was a significant difference between these two devices during the filtration of GWH ($p = 0.000$). The flow rate and turbidity removal efficiency of BSF-Z was found to be significantly superior to that of BSF-S.

Statistical analysis also revealed no significant difference between the means of *Cryptosporidium* and *Giardia* removal by BSF-Z and BSF-S from both synthetic and environmental test water sources ($p > 0.05$). The SIPP vs. CCF indicated a significant difference in removing the oocysts and cysts from surface water ($p < 0.05$), but no significant difference in doing so from groundwater ($p > 0.05$). When comparing the SIPP filter to all other four filters (SIPP vs. CCF, BSF-S, BSF-Z and BF), it was found that the SIPP recorded higher significant performance rates in removing *Cryptosporidium* oocysts from surface and ground water sources. The SIPP filter also demonstrated significant higher performance rates in removing *Giardia* cysts from these water sources when compared with other filters ($p < 0.05$), excepted for the CCF when filtering groundwater collected from Delmas. Similar observation was noted when comparing the efficiencies of the selected HWTS in removing somatic coliphages ($p < 0.05$).

The Pearson's correlation test was performed to establish the degree of correlations between the flow rates, turbidity and microbial removal efficiency of HWTS. A strong negative correlation between the flow rates and the removal of *Cryptosporidium* and *Giardia* by SIPP ($r = -0.742$ oocysts and -0.812 cysts) was detected. A weak negative correlation was noted between the flow rates and the protozoan parasites' removal by CCF ($r = -0.318$ for *Cryptosporidium*) and -0.522 for *Giardia*). A weak positive correlation was observed between the flow rate and removal of *Cryptosporidium* by BSF-Z ($r = 0.392$ for *Cryptosporidium*), while a weak negative one was noted for *Giardia* ($r = -0.182$). Weak positive correlations were also observed between the flow rates and the removal of *Cryptosporidium* and *Giardia* by BSF-S ($r = 0.534$ oocysts and 0.392 cysts) and BF ($r = 0.225$ oocysts and 0.220 cysts). There was a strong negative correlation between the turbidity and the removal efficiencies of SIPP in terms of protozoan parasites ($r = -0.896$ oocysts and -0.743 cysts), CCF ($r = -0.786$ oocysts and -0.733 cysts). Strong positive correlations were found between the turbidity and the removal of *Cryptosporidium* oocysts from BSF-S ($r = 0.765$ oocysts, $r = 0.794$ cysts), BF ($r = 0.955$ oocysts and 0.774 cysts), respectively. The BSF-Z showed weak negative correlations between the turbidity and the removal of *Cryptosporidium* and *Giardia* from all water sources ($r = -0.435$ oocysts and -0.324 cysts).

4. Discussion

Due to the increase in the number of deaths reported every year as a result of drinking contaminated water in developing countries [19], point of use, water treatment systems have been encouraged in rural areas of these countries for the production of safe clean potable water [20]. Although, in this study, *Cryptosporidium* and *Giardia* were not found in test groundwater and surface water sources, these organisms are believed to be generally ubiquitous in water sources and are known to occur in drinking water systems. Treatments to remove and/or inactivate them are known to be effective for a wide range of waterborne parasites [21]. Somatic coliphages and *C. parvum* oocysts can resist a range of environmental conditions and remain viable for a long period of time, which offers a challenge to the water industry [22,23].

To assess the effectiveness of a water treatment system, a monitoring system must be able to determine whether this treatment system is effectively removing hazardous contaminants from any raw water source. In this study, five simple and relatively inexpensive HWTS such as BSF-S, BSF-Z, CCF, BF and SIPP were used. The outcomes of the study revealed that a complete removal (100%) of oocysts only occurred when filtering synthetic water samples through the SIPP filter (Table 6). Most of the selected devices could not produce drinking water that complied with the limit set by the National (SANS 241) and international (WHO) standards for drinking water, which is zero (oo)cysts per 10 L water. It is well known that the infective dose for protozoan parasites is extremely low. In theory, it has been reported that the ingestion of one (oo)cyst is sufficient to cause infection and disease that takes the form of gastroenteritis, diarrhoea, vomiting and anorexia [24]. *G. lamblia* and *C. parvum* are common causes of diarrhoea worldwide. Diarrhoea-related diseases are responsible for approximately 2.5 million deaths annually in developing countries, affecting children, especially those in rural areas where access to a potable water supply and sanitation is lacking [2,25,26]. *C. parvum* causes chronic, severe life-threatening gastroenteritis in immunocompromised patients, and acute but, self-limiting infection in immunocompetent people throughout the world [27]. This protozoan parasite has been considered to be a significant cause of waterborne enteric cryptosporidiosis [28]. Several studies have demonstrated the efficiency of passive immunotherapy or chemotherapeutic agents against *Cryptosporidium*, but significant clinical benefit has still not been demonstrated [29,30]. Taking into account the infective dose of *Giardia* and *Cryptosporidium*, the results of this study clearly indicated that the drinking water produced by the selected HWTSs was not safe for human consumption. Although the performance of the selected devices in removing *Cryptosporidium* oocysts and *Giardia* cysts from environmental water samples did not reach 100%, their efficiency rate was close to this figure, particularly for the SIPP filter (96–99% for oocysts and 97–99% for cysts). Higher significant performance rates of the SIPP filter was noted not only with protozoan parasites but also with viral indicator (somatic coliphages). The effectiveness of this filter was also proved in previous studies by Mwabi and co-workers [20,25]. These authors found that the SIPP was the only device that consistently removed 100% of faecal coliforms, *E. coli*, *Vibrio cholerae*, *Salmonella typhimurium* and *Shigella dysenteriae* from synthetic sterile water, groundwater and surface water sources throughout the study. Its performance was found to be significantly superior ($p < 0.05$) compared to that of the other four devices (60–100% bacterial removals for BSF-S; 90–100% for BSF-Z; 90–100% for CCF; and 40–99.9% for BF) [20,25]. Based on their findings, Mwabi and co-workers recommended the SIPP filter for use by rural communities as it consistently produced

high-quality water that complied with the SANS 241 turbidity and microbiological limits for drinking water. The high performance of the SIPP in removing pathogens from contaminated drinking water sources could be related to the presence of silver nanoparticles impregnated in the clay pot prior to the firing stage during the manufacturing process [31]. Although the concentration of the Ag in the filtrates gradually dropped to 0.22 mg/L after filtration of various water sources up to a total volume of 15 L, this silver concentration was still above the WHO recommended limit, which is 0.1 mg/L [13,20,25]. The present study also supports Lantagne [31] who reported that Potters for Peace filters painted with colloidal silver solution also showed elevated silver concentrations in the filtrate from the first run after the application of silver but that the values obtained (29–61 μg/L) dropped to 20 μg/L or less in the next two runs.

The removal of protozoan parasites by ceramic filters coated with silver has been alleged to be up to 100% [32,33]. The candle ceramic filter used in this study was not impregnated with silver. This might result in lower efficiency rates (oocysts: 92–98%, cysts: 93–98%). Previous investigators have identified that the biological sand filters were capable of achieving a removal efficiency rate of 99.98% of *Cryptosporidium* oocysts in laboratory experiments while no *Giardia* cysts were detected in the treated water [18,34]. However, the removal rates obtained in the present study for both BSF-Z and BSF-S were lower than those stated by these investigators. This may be a result of the smaller size of the filters and the particle size of the fine sand (0.15 mm) used in this study compared to the particle size used in the literature, 0.7 mm [7]. Statically, both biological sand filters performed similarly in removing protozoan parasites during the study. It has been documented that the biological sand filters, as a means of water treatment in homes, reduced diarrheal occurrences by 47–54% [35,36]. Among all the selected home water filtration technologies used in the present study, BF showed a lower performance in removing both the target pathogens and the turbidity (Tables 3 and 6). This is due to the absence of the development of a biological layer that takes place on the surface of the sand bed of a rapid sand filter to enhance the removal of pathogens. Compared with the biological sand filters that have a resting water level, the BF does not have this resting water level which could enhance the removal of microorganisms [35].

Besides the quality of the water produced, the quantity of water produced by HWTSs is also a very important factor as prescribed by the Regulations under Section 9 of the Water Services Act (No. 108 of 1997) of South Africa, which stipulates that the minimum quantity of potable water for basic human activities is 25 L person^{-1} d^{-1} [25]. All the HWTSs used in the present study were able to produce the required quantity of drinking water (Fig. 7). Since their performance of HWTSs in terms of flow rate is directly impacted by the turbidity of the water, turbidity removal was also ascertained during the course of the present study. Of all the HWTS used, SIPP filter demonstrated significant higher performance rates in removing turbidity from groundwater and surface water sources compared with other filters. This could also explain its higher effectiveness in removing the target pathogens and also confirmed the studies by Mwabi and co-workers [20,25]. According to SANS 241, the recommended limit for turbidity in drinking water is <1 NTU while the allowable limit is <5 NTU [37]. In this study, the selected household water treatment technologies reduced turbidity to levels less than 1 NTU (> 90% reduction) in the following order SIPP > CCF > BSF-Z > BSF-S > BF.

A strong negative correlation was found between the flow rates and the removal of *Cryptosporidium* and *Giardia* by SIPP ($r = -0.742$ oocysts and -0.812 cysts) which means that as the flow rates decreased, the protozoan parasites were removed. A weak negative correlation was noted between the flow rates and the removal of these parasites by CCF ($r = -0.318$ for *Cryptosporidium*) and -0.522 for *Giardia*). In other words, fewer protozoan parasites were removed when the flow rate slightly increased. These findings confirm those of previous investigators who have stated that increasing filtration rates decrease the removal of contaminants [38,39]. Weak positive correlations were observed between the flow rate and removal of *Cryptosporidium* and *Giardia* from BSF-Z ($r = 0.392$ for *Cryptosporidium*) and weak negative ones for *Giardia* $r = -0.182$). Weak positive correlations were also observed between the flow rates and the removal of *Cryptosporidium* and *Giardia* by BSF-S ($r = 0.534$ oocysts and 0.392 cysts) and BF ($r = 0.225$ oocysts and 0.220 cysts). In terms of coliphage removal from water sources, significant differences in filter efficiencies were recorded when comparing SIPP with the four other filters ($p < 0.05$) except during the filtration of SWL. Significant difference ($p < 0.05$) in coliphage removals were also noted between the two types of biosand filters. Statistical evidence revealed weak negative correlations between the flow rates of BSF-S ($r = -0.159$), SIPP ($r = -0.004$) and BF ($r = -0.080$) and the average coliphages removed from the water sources when using these filters. When correlating the flow rates with the coliphage removals by BSF-Z ($r = 0.050$) and CCF ($r = 0.105$), weak positive correlations were recorded.

5. Conclusions and recommendations

This study aimed at evaluating promising technologies for local application in the removal of viral indicators, *Cryptosporidium* spp. and *Giardia* spp. In overall, a remarkable decrease in oocysts and cysts was noted in the treated water produced by all the selected HWTS. Nevertheless, the selected systems did not achieve a complete removal of the target protozoan parasites as stipulated in the South African National Standards (SANS 241). Regardless of the quality of the intake water, the effectiveness of the SIPP filter in removing *Cryptosporidium* and *Giardia* species is found to be significantly superior ($p < 05$) to that of the other four filters. The reduction of protozoan parasites to less than one (oo)cyst was in this order: SIPP > CCF > BSF-Z ≥ BSF-S > BF. Statistically, both biological sand filters perform similarly in their removal of protozoan parasites. Furthermore, all the selected HWTS were able to reduce the target viral indicator (somatic coliphages) in test water sources. However, the SIPP filter significantly produces drinking water with a concentration of somatic coliphages within the recommended SANS 241 limits (0–1 pfu/100 mL), regardless of the intake water source (97.7–100% removal efficiency equivalent to 0–3 pfu/100 mL). In spite of its low flow rate, the SIPP filter was found to be a cost-effective promising technology that is suitable for the production of safe drinking water, free of enteric viruses. This study and that of Mwabi and co-workers from 2012 to 2014 have therefore resulted in a better understanding of sustainable HWTS, highlighting the criteria that could assist rural communities in the right choice of filters. More studies are then needed to enhance the efficiency of HWTSs, especially SIPP in achieving their complete removal of all pathogens in order to produce safe drinking water and tremendously eradicate preventable waterborne diseases prevalent in the rural communities of Africa.

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References

[1] WHO/UNICEF, Population with Improved Sanitation Data, World Health Organization and United Nations Children's Fund, Geneva, Switzerland, 2010.
[2] M. Kosek, C. Bern, R.L. Guerrant, The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000, Bull. WHO 81 (2003) 197–204.
[3] W.O.K. Grabow, Bacteriophages: Update on application as models for viruses in water, Water SA 27 (2001) 251–268.
[4] J.B. Rose, C.P. Gerba, W. Jakubowski, Survey of potable water supplies for *Cryptosporidium* and *Giardia*, Environ. Sci. Technol. 25 (1990) 393–400.
[5] K.A. Reynolds, K.D. Mena, C.P. Gerba, Risk of waterborne illness via drinking water in the United States, Rev. Environ. Contam. Toxicol. 192 (2008) 117–158.
[6] G. Ortega-Pierres, H.V. Smith, S.M. Caccio, R.C.A. Thompson, New tools provide further insight into *Giardia* and *Cryptosporidium* biology, Trends Parasitol. 25 (2009) 410–416.
[7] CAWST, Biosand Filter Manual: Design, Construction, Installation, Operation and Maintenance, 2008. Available from http://www.cawst.org/en/themes/biosand-filterURL (Accessed on 24 February, 2010).
[8] T. Uchida, N. Marn, M. Furuhata, A. Fujino, S. Muramoto, A. Ishibashi, K. Koshiba, T. Shiba, T. Kikuchi, J.F. Patzer, S.J. Yao, S.K. Wolfson, Anti-bacterial zeolite balloon catheter and its potential for urinary tract infection control, ASAIO J. 41 (1995) 221–226.
[9] D. Barnes, C. Collin, S. Ziff, The Biosand Filter, Siphon Filter and Rainwater Harvesting: Strategic Recommendations for New Water Treatment Technologies and Safe Water Storage to Pure Home Water, Master of Engineering Project, Massachusetts Institute of Technology (MIT), 2009.
[10] D.S. Van Halem, H. Van Der Laan, S.G.J. Heijman, J.C. Van Dijk, G.L. Amy, Assessing the sustainability of the silver-impregnated ceramic pot filter for low-cost household drinking water treatment, Phys. Chem. Earth 34 (2009) 36–42.
[11] USEPA, *Cryptosporidium* in Water by Filtration, United States Environmental Protection Agency, Method 1622, 2001.
[12] DWAF, South Africa Water Quality Guidelines for Domestic Use, second ed., Pretoria, South Africa, 1996.
[13] M.N.B. Momba, E. Madoroba, C.L. Obi, Apparent Impact of Enteric Pathogens in Drinking Water and Implications for the Relentless Saga of HIV/AIDS in South Africa, Formatex Research Centre, Spain, 2010.
[14] WHO, WHO Guidelines for Drinking Water Quality, World Health Organization, Geneva, 2006.
[15] V.S. Brozel, T.E. Cloete, Effect of storage time and temperature on the aerobic plate count and on the community structure of two water samples, Water SA 17 (1991) 289–295.
[16] USEPA, Hazard Analysis Critical Control Point (HACCP), Washington, DC, 2006.
[17] ISO, Water Quality—Detection and Enumeration of Bacteriophages, International Organization for Standardization, Geneva, 1998.
[18] SANS, Drinking Water Standard, South African Bureau of Standards 241 (SABS), Pretoria, 2006.
[19] S. Malato, P. Fernández-Ibáñez, M.I. Maldonado, J. Blanco, W. Gernjak, Decontamination and disinfection of water by solar photocatalysis: Recent overview and trends, Catal. Today 147 (2009) 1–59.

[20] J.K. Mwabi, B.B. Mamba, M.N.B. Momba, Removal of waterborne bacteria from surface water and groundwater by cost-effective HWTS: A sustainable solution for improving water quality in rural communities of Africa, Water SA 39(4) (2013) 437–448.
[21] M.W. Lechevallier, W.D. Norton, Treatments to address source water concerns: Protozoa, in: G.F. Craun (Ed.), Safety of Water Disinfection: Balancing Chemical and Microbial Risks, ILSI Press, Washington, DC, 1993, pp. 414–425.
[22] F. Freire-Santos, A.M. Oteiza-Lopez, C.A. Vergara-Castiblanco, M.E. Ares-Mazas, Effect of salinity, temperature and storage time on mouse experimental infection by *Cryptosporidium parvum*, Vet. Parasitol. 87 (1999) 1–7.
[23] R. Fayer, U. Morgan, S.J. Upton, Epidemiology of *Cryptosporidium*: Transmission, detection and identification, Int. J. Parasitol 30 (2000) 1305–1322.
[24] L.J. Robertson, A.T. Campell, H.V. Smith, Survival of *Cryptosporidium parvum* oocysts under various environmental pressures, Appl. Environ. Microbiol. 58 (1992) 3494–3500.
[25] J.K. Mwabi, B.B. Mamba, M.N.B. Momba, Removal of *Escherichia coli* and faecal coliforms from surface water and groundwater by HWTS: A sustainable solution for improving water quality in rural communities of the SADC region, Int. J. Environ. Res. Public Health. Special Issue: Drinking Water Health 9(1) (2012) 139–170.
[26] C.L. Obi, E. Green, P.O. Bessong, B. De Villiers, A.A. Hoosen, E.O. Igumbo, N. Potgieter, Gene encoding virulence markers among *Escherichia coli* isolates from diarrhoic stool samples and river sources in rural Venda communities of South Africa, Water SA 30 (2004) 37–42.
[27] P. O'Donoghue, *Cryptosporidium* and cryptosporidiosis in man and animals, Int. J. Parasitol. 25 (1995) 139–195.
[28] R.A. Dillingham, A.A. Lima, R.L. Guerrant, Cryptosporidiosis: Epidemiology and impact, Microb. Inf. 4 (2002) 1059–1066.
[29] J.A. Castro-Hermida, M.E. Ares-Mazas, In vitro and *in vivo* efficacy of α-cyclodextrin for treatment of experimental cryptosporidiosis, Vet. Parasitol. 114 (2003) 237–245.
[30] E.M. Zardi, A. Picardi, A. Afeltra, Treatment of *Cryptosporidiosis* in immunocompromised hosts, Chemotherapy 51 (2005) 193–196.
[31] D.Lantagne, Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter Report 2: Field Investigations, Alethia Environmental for USAID, Boston, MA, 2001.
[32] C.Mattelet, Household Ceramic Water Filter Evaluation Using Three Simple Low-cost Methods: Membrane Filtration, 3 M Petrifilm and Hydrogen Sulfide Bacteria in Northern Region, Ghana, MS Thesis, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology (MIT), 2006.
[33] G. Palmateer, D. Manz, A. Jurkovic, R. McInnis, S. Unger, K.K. Kwan, B. Dudka, Toxicant and Parasite Challenge of Manz Intermittent Slow Sand Filter, Environ. Toxicol. 14 (1999) 217–225.
[34] C.E. Stauber, M.A. Elliott, F. Koksal, G.M. Ortiz, F.A. Digiano, M.D. Sobsey, Characterisation of the biosand filter for *E. coli* reductions from household drinking water under controlled laboratory and field use conditions, Water Sci. Technol. 54 (2006) 1–7.
[35] C.E. Stauber, G.M. Ortiz, D.P. Loomis, M.D. Sobsey, A randomized controlled trial of the concrete biosand filter and its impact on diarrheal disease in Bonao, Dominican Republic, Am. J. Trop. Med. Hyg. 80 (2009) 286–293.
[36] S.K. Tiwari, W.P. Schmidt, J. Darby, Z.G. Kariuki, M.W. Jenkins, Intermittent slow sand filtration for preventing diarrhoea among children in Kenya households using unimproved water sources: Randomized controlled trial, Trop. Med. Int. Health 14 (2009) 1374–1382.
[37] T. Clasen, S. Boisson, Household-based ceramic water filters for the treatment of drinking water in disaster response: An assessment of a pilot programme in the Dominican Republic, Water Pract. Technol. 1 (2006) 1–9.
[38] G. Nakhla, S. Farooq, Simultaneous nitrification and denitrification in slow sand filters, J. Hazard. Mater. 96 (2003) 291–303.
[39] S. Aslan, H. Cakici, Biological denitrification of drinking water in a slow sand filter, J. Hazard. Mater. 148 (2007) 253–258.