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Assessing the Sustainability and Acceptance Rate of Cost-Effective Household Water Treatment Systems in Rural Communities of Makwane Village, South Africa

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Abstract: The current study investigated the acceptance rate and long-term effectiveness of cost-effective household water treatment systems deployed in Makwane Village. A structured questionnaire was used prior to implementation to collect information such as level of education, level of employment, and knowledge about point-of-use water treatment systems in the target area. The long-term effectiveness was determined by factors such as the *Escherichia coli* removal efficiency, turbidity reduction, silver leached, and flow rate of the household water treatment devices. The results of the survey prior to deployment revealed that only 4.3% of the community had a tertiary qualification. Moreover, 54.3% of the community were unemployed. The results further revealed that 65.9% of the community were knowledgeable about other point-of-use water treatment methods. The acceptance rate, which was found to be initially higher (100%), reduced after three months of implantation (biosand filter with zeolite-silver clay granular—82.9%; silver-impregnated porous pot filters—97.1%). Moreover, the long-term effectiveness was determined, taking into consideration the adoption rate, and it was found that silver-impregnated porous pot filters have a long life compared to biosand filter with zeolite-silver clay granular. Although household water treatment systems can effectively reduce the burden of waterborne diseases in impoverished communities, the success of adoption is dependent on the targeted group. This study highlights the significance of involving community members when making the decision to scale up household water treatment devices in rural areas for successful adoption.

Keywords: adoption; acceptance; household water treatment systems; long-term effectiveness

1. Introduction

Access to piped water supply through house connections is the ideal solution to counteract water-related illnesses. Nonetheless, with the financial and political challenges faced by most developing countries, coupled with the high capital and maintenance costs of piped supply systems, centralized safe piped water is likely decades away for most developing regions [1]. According to the WHO [2], an estimated 502,000 people die each year due to diarrhea as a result of drinking unclean water. Early childhood death, especially in the poorest rural areas, is ascribed to an inadequate supply of safe drinking water [3–9]. The WHO [10] has highlighted that properly managed water, sanitation, and hygiene (WASH) services are an indispensable part of preventing disease and protecting human health, especially during infectious disease outbreaks. It is of paramount significant for the government to invest in water and sanitation systems in preparation for disastrous situations. The most important aspect in improving public health is to provide communities with safe and clean water. Point-of-use water treatment systems are, therefore, a solution to addressing water-related diseases which result from the pollution of water sources.

Lack of access to piped water supply systems has forced most underserved rural dwellers of developing countries to utilize common practices, such as water collection from any available source (rivers, springs, community standpipes, and boreholes) and the storage of water in their homes. In most cases, these communities store drinking water in jerry cans, buckets, drums, basins, or local pots to maintain the supply in their homes [11–13]. Even if the drinking water is supplied through piped systems in homes, it is not always available on a regular basis, and therefore the storage of water is still a necessity. However, reports have highlighted that the contamination of safe drinking water collected from a reliable source may happen during transport, handling, and storage, and this has resulted in poor health outcomes [11,13–15].

In South Africa, despite the effort made by the government in terms of the provision of clean water for all and the stipulations of "access to safe drinking water for all" in the South African Constitution [16], access to a sustainable potable water supply is still lacking, especially in rural areas [17]. In spite of reports highlighting that the country achieved the Millennium Development Goal (MDG) 7, which aimed to halve the number of people without access to safe drinking water [18], the survey conducted by Statistics South Africa in 2016 showed that almost 2.6 million of the 16.8 million households surveyed did not have acceptable access to safe drinking water [19]. The South African communities without an adequate water supply are left with no choice but to collect water from any available sources, which may pose a health risk to their lives. The aim of the United Nations Sustainable Development Goal (SDG) 6 is to ensure the availability and sustainable management of water and sanitation for all [20]; however, water that meets the international standards for quality might not be achieved due to financial, infrastructure, and human capital constraints.

The need to control waterborne diseases is of paramount importance to ensure the protection of public health in rural areas of the developing world. Consequently, the scientific community has developed a large number of household water treatment systems. These point-of-use (PoU) water treatment technologies coupled with safe storage have long been proposed as a short-term solution for the provision of safe drinking water and a reduction in the waterborne disease burden in rural communities without access to improved water sources [21–24]. However, achieving the potential of household water treatment systems (HWTS) depends not only on them being made available to the target population but also on them being used correctly and consistently on a sustained basis. Like most health interventions, HWTS must actually reach the target population with safe, effective, appropriate, and affordable solutions. Nevertheless, this can be a formidable challenge, even for an intervention such as a vaccine. Unlike vaccines, HWTS require people to use it on a daily basis to provide maximum protection from waterborne diseases. Even occasionally, the drinking of untreated water may cancel out the potential health benefits of HWTS [24,25]. Allowing the target groups to understand the key characteristics, such as the perception of water quality and usefulness of HWTS as well as added factors such as household income and/or parental education, are essential to enhance the successful adoption of HWTS in developing countries. Thus, the challenge of implementing HWTS lies in providing sustainable treatment methods that can be implemented in a wide range of locations and that are accepted by the end-users. For that reason, this study was carried out between April 2015 and March 2016 to investigate the long-term effectiveness of, attitude to, and acceptance rate of two cost-effective household water treatment systems (biosand filter with zeolite-silver clay granular (BSZ-SICG) and silver impregnated porous pot (SIPP) filters) by the Makwane community in the Limpopo Province of South Africa.

2. Materials and Methodology

2.1. Ethical

This study was conducted taking into consideration the requirement of the ethics clearance approved by the Faculty of Science Research Ethics Committee (FCRE) at the Tshwane University of Technology (TUT), where the study was registered. Access to Makwane Village was obtained through the local pastor and community leaders. Furthermore, authorization to conduct the study was also obtained from the municipal manager, the municipal councilor, and the local municipal committee. All of the households that were selected for participation were given informed consent forms to sign at the beginning of the project. The project expectations and respective obligations by both the participants and investigators were explained and any questions were answered. The participants were not subjected to risks of any kind as a result of the project.

2.2. Household Water Treatment Systems Description

The HWTS [35x BSZ-SICG and 55x SIPP filters (CSIR and Tshwane University of Technology, Pretoria, South Africa)] in this study were modified and implemented in the Makwane community, as previously described [26]. However, for the purpose of this study 70 HWTS (35 SIPP and 35 BSZ-SICG) were assessed for their adoption/acceptance and effectiveness in the Makwane community. These two sets of HWTS assessed in this study were formerly tested for their ability to remove waterborne pathogens [26] prior to being implemented in the Makwane community. In brief, the BSZ-SICG filters consisted of layers of gravel, coarse sand, natural zeolite (Clinoptilolite) (Pratley minerals (PTY) LTD, Johannesburg, Krugersdorp, South Africa), silver impregnated clay granular, fine sand, and two diffusion disks (Figure 1). The natural zeolite particle size used in this study ranged between 1 and 3 mm, with a chemical composition of $(Na,K,Ca)_{2\text{-}3}Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12H_2O$, and was used without any modification. The SIPP filters consisted of a clay pot incorporating silver nitrite and inserted inside a 5-liter plastic bucket, which was mounted on top of a 10-liter plastic bucket that was used as a receiving container (Figure 1). Figure 2 shows the types of HWTS implemented in Makwane Village. Both water filters were constructed by the Tshwane University of Technology with the help of the CERMA Lab (CSIR, Pretoria, South Africa). The two sets of HWTS were found to produce water of good quality prior to their implementation in Makwane Village. A total of 70 households committed to participate in the study, and each of them was given one type of water treatment device (free of charge) randomly. The follow-up was conducted on a weekly basis from the time of implementation for a period of 12 months. In addition, one member of each household was trained on how to maintain the HWTS depending on the type of treatment device given. Briefly, the BSZ-SICG filters were maintained by removing all the layers and washing them individually, and the layers were allowed to dry before being packaged back into the device (Figure 3). In contrast, the SIPP filters were washed by rinsing off the ceramic pot to avoid clogging. In addition, households were given 2 × 25 L (one improved storage container with a spigot installed 5 cm from the bottom and an unimproved storage container without a spigot) for the storage of treated water. The cleaning of the filters was performed by the householders when necessary, and this also depended on the volume of water filtered.

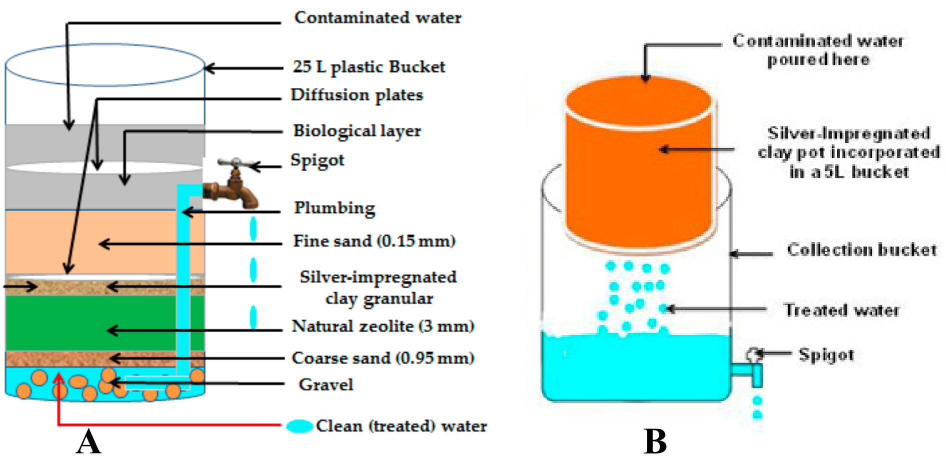

Figure 1. Schematic representation of the Biosand-zeolite silver impregnated clay granular (BSZ-SICG) (**A**) and Silver-impregnated porous pot (SIPP) (**B**) filters showing all layers within the device. Adapted from [26].

Figure 2. The Household water treatment systems (HWTS) implemented in Makwane Village; (**A**) BSZ-SICG filter and (**B**) SIPP filter.

Figure 3. Maintenance of the BSZ-SICG filter implemented in Makwane Village. (**A**) Training of one of the householders on how to wash the layers of the BSZ-SICG filter; (**B**) all five layers after being washed (gravel, coarse sand, fine sand, natural zeolite, and silver-impregnated clay granules); and (**C**) filtered water after the washing of the BSZ-SICG filters.

2.3. Data Collection

The cohort study was conducted between 2015 April and 2016 March (12 months) subsequent to the deployment of the HWTS devices in Makwane Village. Prior to the implementation, a questionnaire was used to collect information on the community, such as level of education, level of employment, and knowledge about PoU water treatment systems. To determine the long-term effectiveness and acceptance rate of HWTS in this village, a survey questionnaire in combination with observations was used to collect information such as (1) "How often do they treat their water with implemented HWTS?", (2) "How do they store treated water?", (3) "How often do they wash the storage containers?", and (4) "Are they willing to buy one of the HWTS?". A scale of 1 to 10 was used (with 10 being the highest and 1 the lowest score) to determine the knowledge of water treatment methods, whereby good knowledge was assigned a score of 7 to 10, fair knowledge a score of 4 to 6, and poor knowledge a score of 3 or less. For the determination of the long-term effectiveness, the HWTS devices were assessed in terms of their performance in flow rate to supply the required water volume of 25 L/person/day, in removing pathogenic bacteria (*Escherichia coli (E. coli)*) and turbidity from untreated water sources, and the level of silver leaching into the treated water over a period of 12 months. Observations and questionnaires were used for determining the number of filters still in use during the study period and the reasons for not being in use (for those that were not in use). All the surveys were conducted in Sepedi, which is the local language of the target community. The respondents included in this study were aged between 17 and ≥37 years and were unemployed during the period of the study, and they were therefore always available to answer the questions. The survey was conducted in all 70 households which showed interest in using the HWTS devices deployed by the TUT Water Research Group.

2.4. Water Quality Assessment

In each household, the flow rates, turbidity, microbial quality of water (*E. coli*), and leaching of silver into the final drinking water were assessed during weekly visits. In brief, the turbidity level of the water samples before and after filtration was determined using a portable turbidity meter (2100P Hach). The turbidity reduction percentages achieved by both HWTS were calculated using Equation (1). The flow rates of both HWTS were measured by recording the volume of water collected from all devices after a period of 1 hour, and calculated using Equation (2). Moreover, the concentration of silver in water treated by both HWTS was monitored on a weekly basis throughout the study period. The SPECTRO ARCOS ICP spectrometer (SPECTRO Analytical Instruments (Pty) Ltd., Kempton Park, Johannesburg, South Africa) was used to detect and determine the concentration of silver in the treated water samples.

$$\%\ turbidity\ reduction = \frac{turbidity\ unfiltered - turbidity\ filtered}{turbidity\ unfildered}\ X\ 100 \quad (1)$$

$$Flow\ rate\ of\ HWTS = \frac{Volume\ of\ water\ filtered}{Time\ (1\ hour)} \quad (2)$$

The enumeration of presumptive *E. coli* before and after treatment was conducted using standard methods (APHA, 2001). Briefly, the spread plate technique was used in this study, whereby a 250 µL aliquot of each water sample (untreated and treated) was spread on MacConkey agar plates (Merck, Johannesburg, South Africa). The plates were then incubated overnight at 37 °C, and thereafter presumptive *E. coli* colonies were counted and recorded as colony-forming units per milliliter (CFU/mL). The arithmetic mean Log bacterial reductions were calculated using Equation (3) and were converted to the *E. coli* percentage removed (Equation (4)), as previously described by [27]:

$$\begin{aligned} Log\ reduction\ &= (Log10\ bacterial\ counts\ before\ filtration \\ &\quad -Log10\ bacterial\ counts\ after\ filtration) \end{aligned} \quad (3)$$

$$\%\ E.\ coli\ removal = 100 - \frac{survival\ counts}{initial\ counts} \quad (4)$$

3. Results

3.1. Level of Education in Makwane Community during the Study Period

Table 1 below provides a summary of the level of education in the Makwane community during the study period. The results revealed that most of the Makwane community were uneducated, with only 4.3% of the households surveyed either having a tertiary qualification or still being at university/college. Of all the surveyed households, 52.9% had dropped out of secondary/high school, while 31.4% dropped out of primary school. Moreover, 11.4% of the surveyed households did not attend school.

Table 1. Level of education in the Makwane community during the study period.

N = 70		
Category	**Frequency**	**Percentage**
Primary school	30	31.4
Secondary/high school	47	52.9
Tertiary institution	3	4.3
None	8	11.4

3.2. Level of Employment in Makwane Community during the Study Period

The results of the survey revealed that most of the Makwane community were unemployed and they depended on social welfare grants (54.3%) and other sources of income (5.7%). Only 4.3% of the Makwane community had professional jobs during the study period, while 35.7% had non-professional jobs. All the results are illustrated in Table 2 below.

Table 2. Level of employment in the Makwane community during the study period.

N = 70			
Category		**Frequency**	**Percentage**
Employed	Professional jobs	3	4.3
	Non-professional jobs	25	35.7
Unemployed	Social welfare grant	38	54.3
	Other	4	5.7

3.3. Knowledge of Water Treatment Methods and Practice in Makwane Village Prior to the Implementation of HWTS

The results of the survey revealed that the majority (65.9%) of the households knew about household water treatment methods (boiling and use of liquid bleach) and 34% of the community members had no knowledge of any household water treatment (HWT) methods. Furthermore, the results revealed that almost the entire community did not treat their drinking water prior to use (81%). Of all the surveyed households of Makwane community, only 11% were found to treat their drinking water with liquid bleach, while 8% used the boiling method. Figure 4 depicts the results of the water treatment methods used by the Makwane community.

3.4. Relationship between the Knowledge of Water Treatment Methods and Selected Demographic Profiles Prior to Implementation

Table 3 shows the results of the relationship between the knowledge of water treatment methods practiced by the Makwane community and the selected demographic profile. The results showed a relationship between the age of the participant/household and the knowledge of the water treatment methods. It was found that 57% of the group aged 32–36 years had a good knowledge of the household water treatment methods used in Makwane Village, as compared to the age group of 17–21 years

(22.1%). Moreover, the level of education was also found to be associated with knowledge of water treatment systems. Participants/households with a secondary/high school qualification (77.1%) were found to be more knowledgeable about the treatment methods as opposed to participants/households with a primary school education (8.6%). Almost none of the participants/households with a primary school education (81.8%) knew about the water treatment methods used in the Makwane community.

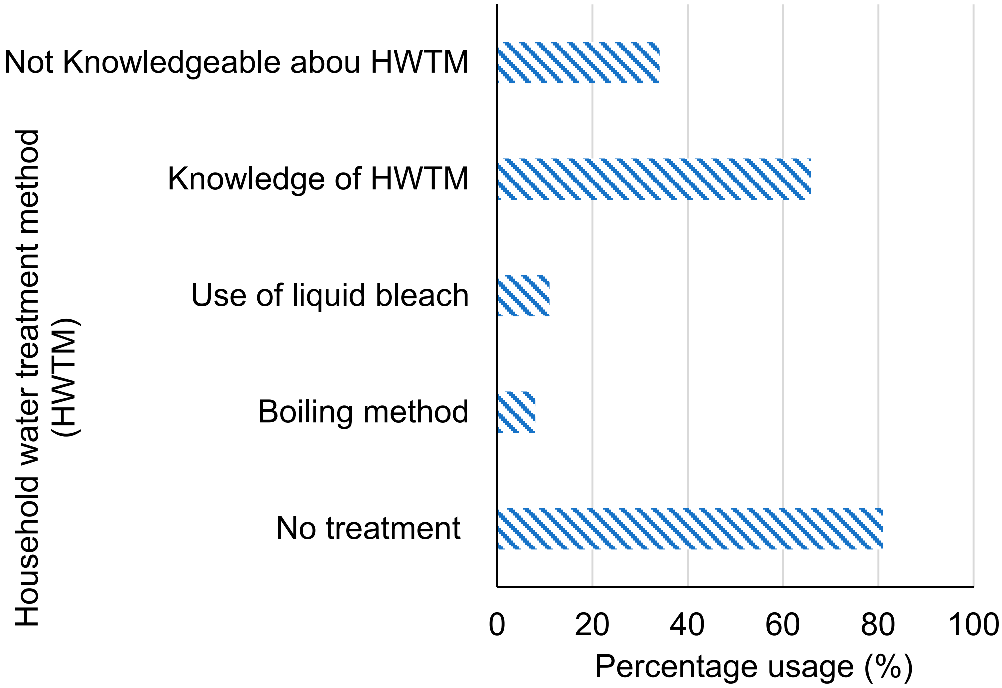

Figure 4. Water treatment methods practised in the households of Makwane Village during the study period.

Table 3. Relationship between the knowledge of practised household water treatment methods and selected demographic profiles in Makwane Village prior to the implementation of HWTS.

Variables	**Knowledge of Boiling and Liquid Bleach Methods N = 70**		
Age Group	**Good**	**Fair**	**Poor**
	Frequency (%)	**Frequency (%)**	**Frequency (%)**
17–21	2 (22.1)	1 (11.1)	**6 (66.7)**
22–26	8 (44.4)	3 (16.7)	**7 (38.9)**
27–31	7 (50)	2 (14.3)	5 (35.7)
32–36	12 (57)	5 (24)	4 (19)
≥37	3 (37.5)	1 (12.5)	4 (50)
Level of education			
Primary	3 (12.5)	3 (12.5)	18(75)
Secondary/High school	27 (71.1)	8 (21.0)	3 (7.9)
Tertiary level	3 (100)	0 (0)	0 (0)
none	2 (40)	2 (40)	1 (20)

3.4.1. Number of Household Water Treatment Systems in Use during the Study Period and Reasons for Not Being in Use for the Determination of Acceptance Rate

Table 4 provides a summary of the results obtained during visits to the Makwane community. The number of HWTS devices in use was obtained through observations during sampling, while the reasons for not being in use were obtained through a questionnaire. The results revealed a greater loss of interest in using the BSZ-SICG filters in the village, from 35 systems (100%) during the first three months of the study down to five systems (20.0%) during the last three months of the study. Moreover, the reasons for the BSZ-SICG filters not being in use were almost the same, with the majority of the households indicating that the water had a bad smell. In contrast, the results indicated that the decrease in the use of the number of SIPP filters (from 35 (100%) to 19 (54.3%) filters) was due to the filters being damaged.

Table 4. Number of household water treatment systems in use throughout the study period and the reasons for not being in use.

Assessment Period	Bsz-Sicg Filters N = 35	Sipp Filters N = 35	Reason for Not in Use
April–June 2015	35 (100%)	35 (100%)	N/A
July–September 2015	29 (82.9%)	35 (97.1%)	**BSZ-SICG**: Water had bad smell. **SIPP**: Filters got damaged.
October–December 2015	16 (45.7%)	22 (66.9%)	**BSZ-SICG**: Bad smell, no time for maintenance (time consuming), broken spigot. **SIPP**: Damaged.
January–March 2016	07 (20.0%)	19 (54.3%)	**BSZ-SICG**: Bad smell, time consuming during maintenance, no time for treating water. **SIPP**: Damaged, flow rate too slow (time consuming).

3.4.2. Survey Subsequent to the Implementation of the HWTS Devices in Makwane Village for the Determination of Acceptance and Adoption Rates

A survey was conducted using a questionnaire subsequent to the implementation of the HWTS devices in order to determine the acceptance and adoption rate. The results (Table 5) revealed that the majority of the Makwane community members used the implemented HWTS only when they needed to use water (77.1%). The results further showed that even though they treated the water, 72.9% stored treated water in other storage containers (any available containers other than the improved or unimproved containers they received) rather than in the improved storage containers (11.4%). Moreover, the results highlighted that the majority of the community washed their storage containers only when dirt was visible (80%). It was also shown that, of the two HWTS devices (SIPP and BSZ-SICG filters) implemented in Makwane Village, the majority of the community members preferred the SIPP filter (80%) to the BSZ-SICG filter (20%). Nonetheless, the majority of the community members showed no willingness to purchase either of the two HWT devices (84.3%).

Table 5. Responds obtained during the survey subsequent to the implementation of HWTS in Makwane community.

Survey Questions		Participant's Responds N = 70
How often do they treat their water with implemented HWTS?	When needed	54 (77.1%)
	On a daily basis	4 (5.7%)
	Never	12 (17.1%)
How do they store treated water?	Improved storage container	8 (11.4%)
	Unimproved storage container	11 (15.7%)
	Other	51 (72.9%)
How often do they wash the storage containers?	When dirty (visible dirt)	56 (80%)
	Once a week	8 (11.4%)
	Never	6 (8.6%)
Are they willing to buy one of the HWTS?	Yes	4 (5.7%)
	No	59 (84.3%)
	Not sure	7 (10%)

3.5. Long-Term Effectiveness of the HWTS Based on Their Performance

3.5.1. Long-Term Effectiveness Based on the Flow Rate and Turbidity Removal

Figure 5 below depicts the long-term effectiveness of the flow rate and the turbidity removal of the BSZ-SICG and SIPP filters for the period of the study (12 months). The results revealed that the flow rates of both water treatment systems were fluctuating. This was because of the maintenance (washing) of the systems (Figure 3). The flow rates were shown to have decreased from 38.7 and 27.5 L/h to 17.6 and 18.4 L/h for the BSZ-SICG and SIPP filters, respectively. The results for turbidity removal showed a gradual decrease from 99.5% to 95.2% for SIPP filters, while for the BSZ-SICG filters there was a rapid decrease (98.6% to 63.5%).

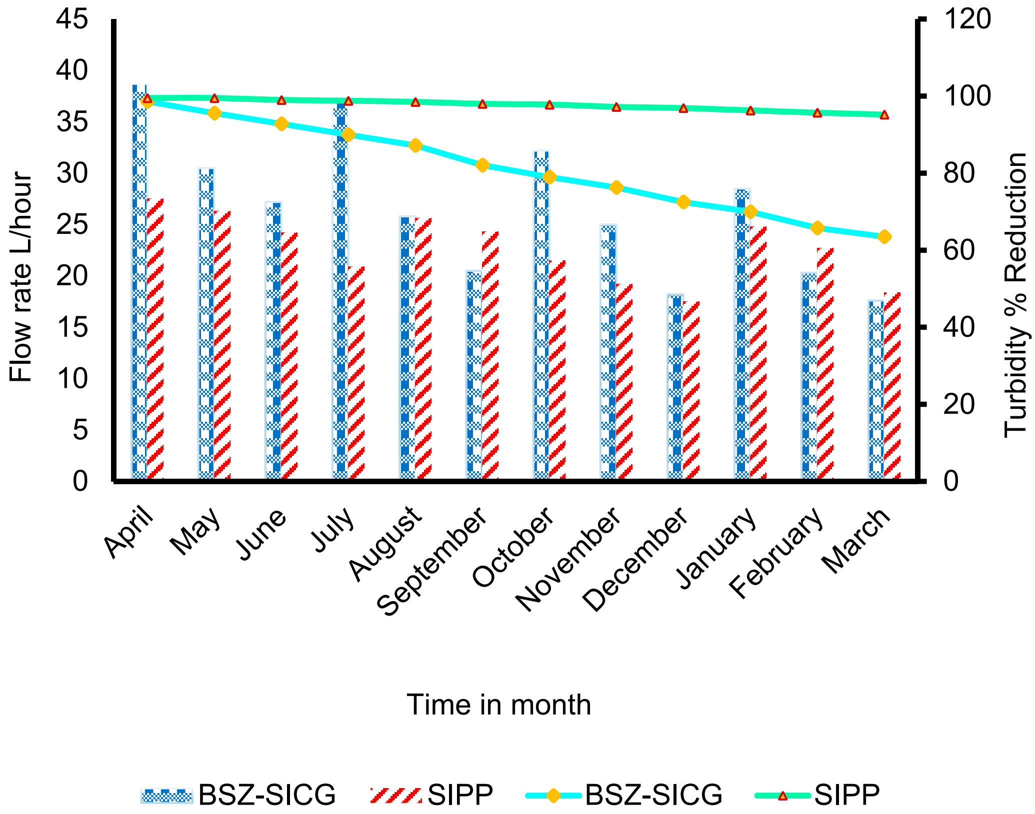

Figure 5. The arithmetic mean turbidity reduction (%) and flow rate in L/hour of the BSZ-SICG and SIPP filters versus time in months.

In addition, Table 6 showes the arithmetic mean results of the efluent and influent turbidity. The turbidity of the influent was found to be high form April (86.7 NTU) to September (26.82 NTU) and started to decrease from October (12.24 NTU).The turbidity for both water treatment devices was found to be within the recommended limit of less than 5 NTU for drinking water.

Table 6. The arithmetic mean results of the influent and effluent turbidity during the study period.

Time in Month	Influent Turbidity (NTU)	Effluent Turbidity (NTU)	
		SIPP Filters	BSZ-SIGC Filters
April	86.7	0.43	1.21
May	66.9	0.33	2.94
June	65.0	0.65	4.68
July	33	0.40	3.3
August	28.67	0.43	3.67

Table 6. *Cont.*

Time in Month	Influent Turbidity (NTU)	Effluent Turbidity (NTU)	
		SIPP Filters	BSZ-SIGC Filters
September	26.82	0.54	4.8
October	**12.24**	**0.23**	**2.57**
November	16.67	0.47	3.95
December	15.75	0.49	4.33
January	12.33	0.47	3.7
February	13.37	0.57	4.68
March	13.42	0.64	4.9

3.5.2. Long-Term Effectiveness Based on the *E. coli* Removal Efficiency and Leaching of Silver in Treated Water

Figure 6 illustrates the continuous removal of *E. coli* and the level of silver leaching into treated water. During the deployment of the HWTS devices, the BSZ-SICG and SIPP filters were shown to have an *E. coli* removal efficiency of 99.99% and 100%, respectively, and the leaching of silver for both the filters was within the standard limits set by the WHO (0.1 mg/L). However, the removal of *E. coli* by BSZ-SICG was characterized by fluctuations, while a progressive decrease in silver concentrations was observed between April and December; thereafter, no silver residual was detected for the rest of the study period. Overall, it was noted that the performance of the BSZ-SICG increased after it was washed at three-month intervals. The efficiency of SIPP filters at removing *E. coli* remained almost constant from April to December, even though the silver concentration decreased progressively. On the 12th month, the SIPP filters showed to be more effective in removing *E. coli* (96.6%) compared to the BSZ-SICG filter, which showed a decrease of up to 50.2%. Furthermore, over the period of 12 months, the concentration of silver leaching from the filters was observed to be very low, less than 0.002 mg/L for both the BSZ-SICG and SIPP filters.

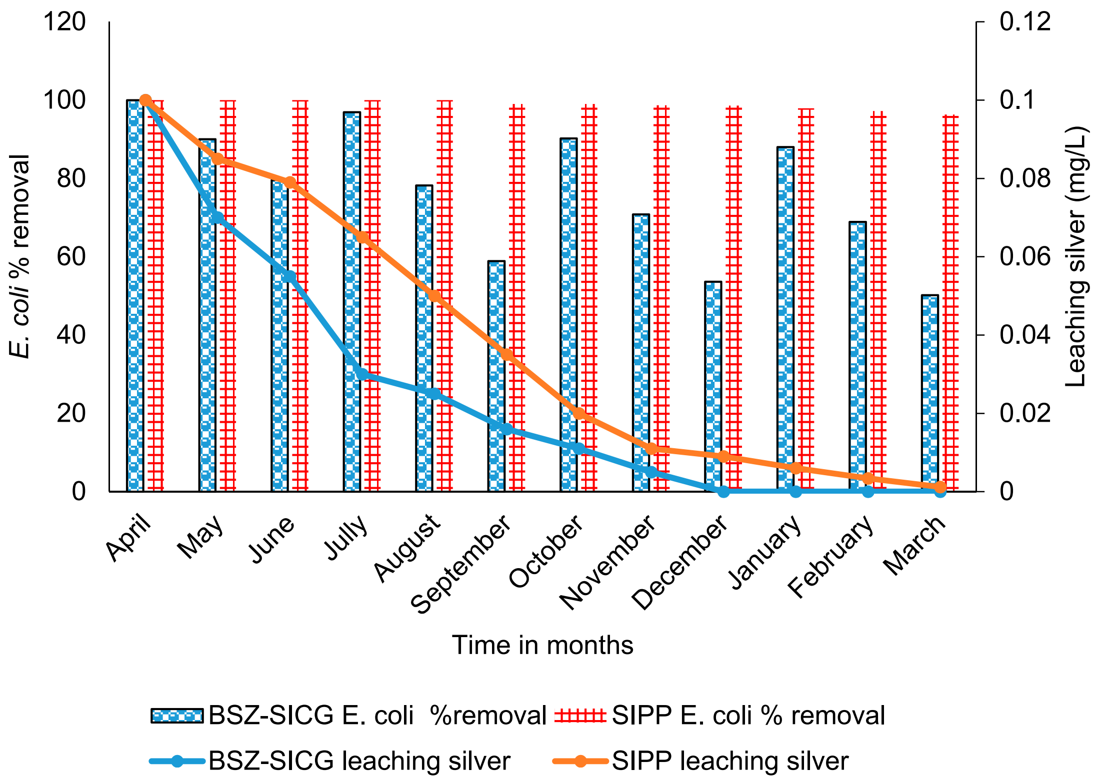

Figure 6. Arithmetic mean of *E. coli* % removal and the concentration of silver leached from the SIPP and BSZ-SICG into treated water versus the time in month.

4. Discussion

Household water treatment coupled with safe storage has long been proposed as an interim solution for the provision of safer drinking water and a reduction in the burden of water-related disease [28]. However, the adoption of HWTS is dependent on the user's preferences. This study assessed the adoption/acceptance rate and the long-term effectiveness of the cost-effective HWTS implemented in the Makwane community. The first approach of this study was to determine the educational and employment level and to assess the knowledge and adoption of water treatment methods practised by the Makwane community. The results of the survey highlighted that the majority of the community members had dropped out of secondary school (52.9%), with only 4.3% of the members having completed tertiary education (Table 1). The high drop-out percentage observed in this study might have contributed to the low adoption rate of known water treatment methods by Makwane community members due to lack of knowledge. In addition, it was also found that more than half (54.3%) of the households in Makwane community depended on social welfare grants (Table 2). The government's intervention is required to subsidize underserved communities with HWT devices in order to improve the health status of rural communities which have no access to a piped water supply.

It was further highlighted in this study that most of the people in the Makwane community were knowledgeable (65.9%) about other methods of treating water at PoU (i.e., boiling and the use of liquid bleach). However, the results showed that only 19% of the Makwane community were applying those methods at PoU (Figure 4). In most cases, the reasons for adoption were dependent on the user's interests and preferences. Furthermore, in order to understand the reasons of why the Makwane community members were not using the known methods to treat their water before drinking, the participants were asked a number of questions. Some of the reasons given by participants for not using the PoU methods are as follows: (i) Affordability—most of them are unemployed; the limited income from the government grant does not allow them to purchase the liquid bleach that is used for the treatment of drinking water in the dwellings. Although the liquid bleach might be seen to be inexpensive to others, it might be expensive to rural dwellers who solely depend on social grants. (ii) The lack of energy supply in dwellings (it takes a lot of energy to boil water and it is exhausting to fetch firewood from the forest). (iii) The majority of the community members have a perception that their water is clean; therefore, it is not important to treat it before use. In spite of this overall perception, some respondents were aware of the fact that their water is of poor quality, but they could not treat it because they could not afford to purchase the liquid bleach. These findings show that there is still a dire need to educate rural dwellers about the importance of treating water before use.

Furthermore, to ascertain the determining factor that might have contributed to the low adoption of household water treatment methods (boiling and the use of liquid bleach) by the Makwane community, selected demographic features were compared with the knowledge of household water treatment methods. The participants were grouped according to their age, and it was found that the participants of the age group 32 to 36 years had a good knowledge (57%) of HWT methods used by the Makwane community as compared to the other age groups (Table 3). This could be related to the fact that most of the participants in this age group had matric and some had tertiary education, which implies that education is a powerful tool in the community and can save lives in vulnerable populations. In addition, the relationship between the level of education and knowledge of the HWT methods was also determined. The results showed that people with a tertiary education were highly knowledgeable (100%) about the methods of treating water at PoU, follwed by the group with a secondary education (71.1%). These results, therefore, prove that education plays a vital role in the community. The level of education can therefore be a contributive factor to accelerate the adoption rate for HWTS in ruralcommunities.

The reasons for the poor acceptance of water treatment technologies are quite complex and understudied [29–31]. In this study, various determinant factors including questionnaire responses and selected demographic characteristics were used to determine the adoption and acceptance rate of the household water treatment systems. The results of the survey revealed that all the Makwane community accepted the installation (100%) of both HWTS devices (Table 4). However, after three months of implementation, it was observed that some of the households had stopped using the devices. One of the reasons given by the participants who had withdrawn was that the spigots were broken and they could not replace these because of their lack of jobs. Other reasons given were that the BSZ-SICG produced water with a bad smell and that it takes time to treat water. According to Walch (1992), biofilm formation in drinking water systems can influence the taste and odor of drinking water. Therefore, the bad smell of drinking water produced by the BSZ-SICG filter in this study can be attributed to the formation of biofilm on the inner surface of the filter due to the fact that the householders were not using these systems on a daily basis. Nonetheless, the importance of the taste and smell of drinking water has been previously highlighted [29,32,33]. In a study by Wright and co-authors (2012), some respondents reported that the water was tasteless, while others described the water as bitter. This feedback clearly indicates the participants' preference for drinking water to have a taste similar to that of untreated water [33]. It is therefore of utmost importance to address this sensitive aspect for a successful acceptance of water treatment technology interventions.

Although the community accepted the HWTS, they were not utilising them fully, as it was observed that only 5.7% treated their water on a daily basis, while 77.1% treated their water only when needed (Table 5). Previous studies have shown that only those households that regularly treat their water will experience the maximum health benefits of household water treatment methods [34]. However, it has been reported that households often do not treat water regularly and even abandon household water treatment methods over time [25,35,36]. The results of this study therefore corroborate the findings of those earlier studies. Moreover, more than three quarters of those community members who were treating their water were found to store it in other containers (72.9%) rather than in the improved containers (11.4%) provided to them. As a result, this inappropriate practice could cancel the health benefits of the HWTS devices. It was highlighted in the literature that the microbiological quality of water deteriorates in homes during storage due to unhygienic practices of storing water in homes [37–39], leaving the water unsafe for human consumption [37,38,40]. Moreover, the results of the survey in this study showed that 80% of the participants washed their storage containers only when dirt was visible. This could contribute to the formation of the biofilm on the inner surface of storage vessels, which has been reported to offer a suitable medium for the growth of microorganisms and consequently to contribute to the deterioration of drinking water quality in homes [41,42]. The results thus indicate that there is still a need for educating rural dwellers on good hygiene practices in the home for better health.

In order to determine the adoption rate of the HWTS, the systems must first be accepted. Moreover, the acceptance of the systems by the users does not mean that they will automatically adopt them. In this study, the adoption rate was determined by the number of HWTS devices that were still in use during the last month (12^{th}) of the survey. It was found that the rate of adoption for the BSZ-SICG (20.8%) and SIPP (54.3%) filters differed (Table 4). The variation in adoption rates for the two HWTS devices could be attributed to the users' preferences based on the appearance and portability of the systems. The SIPP filters were much lighter compared to the BSZ-SICG filters, therefore it was very easy for the users to carry them and to maintain these filters (maintenance in terms of cleaning the system), unlike the BSZ-SICG filters, which are heavy. This aspect added to the preferences of the users. Moreover, in addition to the preferences, willingness to purchase the HWTS was also found to contribute to the adoption rate. When the participants were asked which HWTS device they preferred, most of the respondents (80%) indicated that they preferred the SIPP filter, while 20% preferred the BSZ-SICG filter. This further proves that the appearance and portability of HWTS are of crucial importance during implementation. However, when the participants were asked whether they would purchase any of these HWTS devices in future, 84.3% said no, while only 5.7% said yes (Table 5). This could have been influenced by the lack of sufficient income due to the high unemployment rate in the village (60%), which contributed to the community's inability to afford the devices. These findings show that there is a dire need for the governments in African countries to subsidise household water treatment systems or collaborate with non-governmental organisations and the private sector in manufacturing and implementing HWTS devices in underserved communities.

The key factors influencing the sustainable use of HWTS devices are the acceptance and adoption rate by the end-users. In this study, however, the long-term effectiveness was determined by the flow rate produced and turbidity reduction achieved by these HWTS devices during the study period of 12 months. The flow rate of the HWTS can play a role in acceptance and adoption of the systems by the users simply because of the large quantity of water produced and the fact that it saves time. Upon implementation, the flow rate of the BSZ-SICG filter was 38.9 L/h and that of the SIPP filter was 27.5 L/h; the amount of drinking water produced was thus within the recommended limits of 25 L/person/day set by the WHO (2006). The flow rate of both the systems was observed to decrease over time, and′ during the third month of the survey, the flow rate of the BSZ-SICG and SIPP filters decreased to 27.2 and 24.2 L/h, respectively (Figure 5). The decrease in flow rates for the BSC-SICG was caused by the fine sand which accumulated at the bottom of the water treatment systems, while the decrease in flow rates for the SIPP filters was found to be caused by clogging caused by small/fine particles found in the source water. These findings were in line with the findings of previous investigators [43], who found that the flow rates of the BSF-S and BSF-Z declined after filtering 40 L of a water sample. The BSZ-SICG filters were washed during the third month of being in use when the flow rate was at 27.2 L/h, and a drastic increase in the flow rate to 37.4 L/h was observed. Moreover, the SIPP filters also showed a decrease in the flow rate; however, the decrease was slower than that of the BSZ-SICG. The SIPP filters, unlike the BSZ-SICG filters, were washed (Figure 5) during the fourth month of being in use and they showed an increase in flow rate to 25.6 L/h. In addition, the results in this study showed that decreases in flow rates has a negative influence on the turbidity of inffluent (Table 6). Futhermore, it was noted that the turbidity of the influent was very hihg between April and September, and start to decrease from October. In most cases, the influent turbidiy variation is attributed to change in seasons whereby, it is reported to be mostly high in wet seasons [44]. However, in this study, the decrease in influent turbidity from October was due to sedimentation, as the householders where adviced to allow their water to settle before filterring for the effective results. Moreover, the turbidity of the effluent was found to decreases subsequent to the washing of the water treatment devices. This, however, was noted in the BSZ-SICG filters, whereby the decrease in turbidity was attributed to the fine sand that penetrates all the layers to the bottom of the device. These findings imply that the BSZ-SICG and SIPP filters must be washed every two to three months of being in use, depending on the amount of water filtered and the quality in terms of turbidity for the production of safe clean drinking water.

Moreover, the long-term effectiveness of the systems in this study was also measured by the ability of HWTS to remove *E. coli* from source water and the level of silver leached in treated water (Figure 6). Although cleaning/maintenance of the BSZ-SICG filters was shown to have a positive effect on increasing the removal efficiency of *E. coli* from source water, the percentage removal of *E. coli* was shown to gradually decrease with a decrease in the silver concentration. These results simply imply that the silver concentrations in HWTS have a significant effect in removing *E. coli* from source water, provided that the water treatment devices are maintained. Furthermore, the decrease in the flow rate of the HWTS was found to have a negative impact on the *E. coli* removal efficiency. Thus, it was observed in this study that when the flow rate decreased, the *E. coli* removal efficiency of the HWTS also decreased. During implementation, the *E. coli* removal efficiency of the BSZ-SICG filter was 99.99%, but it decreased to 79.6% after three months of use, and then again increased to 96.9% during the fourth month after being washed. The presence of *E. coli* in the treated water was attributed to the accumulation of fine sand at the bottom of the systems, which was removed by washing the systems. Furthermore, the *E. coli* removal efficiency of the BSZ-SICG filter gradually decreased as the silver concentration was depleted in the systems (Figure 6). These findings further prove that, with proper maintenance (the washing of the HWTS), the BSZ-SICG filters can produce safe drinking water and continue to save lives in vulnerable communities. In contrast, the washing of the SIPP filters did not have any effect on the *E. coli* removal efficiency, as the results showed continuous and gradual decrease in the *E. coli* % removal even after washing the filters.

5. Conclusions

In this study, the acceptance/adoption rate together with the long-term effectiveness of the HWTS implemented in Makwane Village was determined. It was found that the user's preference is the key factor in enhancing the acceptance and adoption rate of HWTS devices in communities. It is thus vital for consumera' preferences, choices, and aspirations to be taken into consideration for a successful scale-up of HWTS in underserved communities. Above all, finance was found to play a major role in the adoption rate, as it was noted in this study that the majority of the community showed no willingness to purchase HWT devices in the future due to the high unemployment rate in the community. The intervention of the government is therefore needed for subsidizing HWTS in impoverished rural communities. In addition, the life span of the HWTS depends on the maintanance of the devices; thus, the microbiological quality of water deteriorates over time when the BSZ-SICG filters are in use and improves when the filters are washed. However, the washing of the SIPP filters did not have an impact on the quality of water. Maintenance, therefore, plays a key role in the long-term effectiveness of the HWTS. Consequently, it is important to train the users on how to maintain the HWTS devices for sustainable use.

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