Post-implementation Effectiveness of Selected Household Water Treatment Technologies used in Rural Kenya

Highlights
- The four household water treatment technologies (HWT) assessed (Aquatab, Ceramic filter, PUR, Waterguard), improved drinking water microbial quality, even though external support had been withdrawn one to two years prior to the study.
- However, inadequate knowledge and poor user behaviour reduced the effectiveness of the HWT technologies to below the expected baseline log reduction values.
- In spite of their proven efficacy in laboratory and short-term field studies, user education on the critical steps of HWT use and the selection of appropriate HWT options are necessary for maintaining HWT effectiveness in typical use situations.
- Provision of improved water sources is the first step towards protecting the health of users, and enforcement of adherence by practitioners to the stipulated standards for development of these water sources.

Introduction
The use of decentralised water supplies is a major strategy being used to meet the Millennium Development Goal 7 (MDG 7). Though piped water can be contaminated, decentralised community water supplies are especially vulnerable to recontamination because users need to collect, transport and store the collected water (Younes and Bartram, 2001 and Clasen et al., 2007).

Recontamination has been observed in Kenya where a baseline survey of 22 districts in Kenya found evidence that 62% of the water sources which had been safe at source had become microbiologically contaminated during collection, storage and use in the home (UNICEF, 2010).

There is a global recognition of the importance of maintaining the microbiological quality of drinking water from the source to the point-of-use to reduce water, sanitation and hygiene-related diseases. These diseases are responsible for 7% of all deaths and 8% of all disability adjusted life years (DALYs) lost in developing countries (Mara, 2003). The microbiological quality of drinking water supplies can be maintained till the point-of-use either by providing household connections, which some authors argue is not financially feasible (Stevenson, 2008) or by using low-cost household water treatment technologies (WHO, 2007).

The World Health Organisation recommends the use of HWT by households who rely on unsafe water sources and those that use piped water of intermittent supply and of uncertain quality.

The use of HWT is important in sub-Saharan Africa where 37% of the 884 million people who use unimproved water sources live (WHO/UNICEF, 2012). HWT is also relevant in Kenya were two out of every five persons has inadequate access to safe water (WHO/UNICEF, 2012).
It is however unclear why, in spite of the fact that rural African households need household water treatment (HWT) most, they are the least likely to use them (UNICEF/WHO 2011; Pg 41).

Furthermore, a school of thought doubts the effectiveness of HWT (Kirchhoff et al., 1985; Eisenberg et al., 2007), while another school of thought argues that even if they are effective under laboratory and field conditions they may not continue to be so over long periods of use (Sobsey et al., 2008).

These differences in opinion hinder large-scale promotion and uptake of HWT technologies and their inclusion in national development plans.

In recognition of this debate within the sector, a study was conducted by Rhodes University, South Africa with funding support of UNICEF Kenya to assess the effectiveness of selected HWT technologies under typical-use conditions after external HWT promotion and follow up has ceased.

**Study questions**

1. What are the knowledge, attitudes and practices (KAP) of the study communities in relation to household water treatment?
2. What is the likelihood of adopting and complying with HWT technologies based on the perceived value households attach to the technologies?
3. Do HWT users like the taste of chlorinated turbid drinking water?
4. At which stage between the source to the point-of-use does the highest contamination occur and how does the quality of stored water relate to household knowledge, attitude and practices?
5. How effective are the selected household water treatment technologies after the promotion/trial period?
6. What is the potential health impact of the selected HWT technologies?

Figure 1 shows the conceptual framework of the study, the research questions, the basis of analysis and the data collection tools.

This field note addresses study question five of the study.

**Method**

The study assessed the performance of Waterguard, PUR, Aquatab and Chujio ceramic filters. These were the methods that had been promoted by the intervening NGOs and were still being used in the study area. The exception was solar disinfection which was not used by any of the study households. The assessment was conducted after the implementing organisations Kenya Water and Health Organisation (KWAHO) and Safe Water and Poverty Project (SWAP) had stopped all HWT interventions in the study communities; KWAHO — one year prior to the study and SWAP — two years prior.

The assessment was conducted in five intervention villages in the Nyanza province of Kenya. The study area was typically rural; the households were poor and socio-economically disadvantaged with poor access to social and environmental health infrastructure. A total of 37 households who had self-reported HWT use and were observed to have the HWT products were assessed in the five selected villages.

Unannounced visits were paid to each of the selected households in the rainy season between April and May 2011, to collect water samples from the source, collection and storage points. The water samples from the household collection containers represented the water quality before treatment and samples from the storage container, the quality after treatment. The storage containers were not sterilised and users were not given additional hygiene education such as handwashing so as to mimic typical-use and real-world conditions.

Each household was assessed three times, a total of 247 water samples were collected and a total of 98 questionnaires were administered.

Data analysis was carried out using the following aggregate measurements:

a) Geometric and arithmetic means of E.coli/100 ml and total coliforms/100 ml.

b) The base 10 log reductions in E. coli and total coliform concentrations before and after treatment.

c) The percentage reductions in the indicator organisms before and after treatment with each HWT technology.

d) The proportion of acceptable samples that complied before and after treatment, with the WHO (2008) drinking water standards for E. coli and the Sphere project (2004) standards for total coliforms.
Figure 1 Conceptual framework of study

**Question**

What is WASH KAP of rural communities and implication for water quality and effective HWT?

What implications do the perceived value rural households attach to HWT hold for their adoption of and compliance with HWT?

Do changes in water quality between source and point-of-use suggest a need for HWT? And what is the relationship between stored water quality and household KAP?

How effectively can the HWT technologies treat water when used by the households without external support, post-implementation?

Do the HWT technologies reduce exposure to and probability of infection from water-borne pathogens when used by rural households?

**Basis of comparison**

- Intervention and control
- Intervention and control
- Improved and unimproved sources used by intervention and control communities
- Improved and unimproved sources used by intervention communities
- Improved and unimproved sources used by intervention communities

**Tool**

- Questionnaire
- Questionnaire and free chlorine residual test
- Questionnaire and physico-chemical water quality tests
- Questionnaire and microbiological water quality tests
- Microbiological water quality tests
The results from a–d were used to assess each HWT method based on the following criteria:

a) Microbial efficacy;

b) Robustness — the ability to effectively treat water with a high microbial load (Sobsey et al., 2008); and


Results

Context of the assessment

Most of the households assessed (67.9%) used unimproved water sources, which was mainly surface water (60.2%). A third (34.02%) used improved water sources, mainly rainwater (24.9%).

The mean turbidity of all the drinking water sources exceeded the WHO standards of 0.1 NTU (range 4.63 NTU: public standpipe to 210 NTU: surface water). Rainwater had a mean turbidity of 10.28 NTU.

The majority of households (91.48%) treated water on the days of the assessments and about two thirds of them treated 20 l/day. During the three assessments, the unimproved sources consistently had higher E. coli concentrations than the improved sources.

Microbial efficacy

Each of the four HWT technologies increased the percentage of samples that complied with sector standards after treatment of household water sources. There was no significant difference between the technologies in the percentage of increase after treatment. The percentage of combined samples that complied with the drinking water standards for E. coli increased with the use of ceramic filters by 67.7%, Aquatab by 37.5%, Waterguard by 36.7% and PUR by 25% (Table 1).

Table 1 shows that despite the increase, a substantial percentage of samples did not comply with drinking water standards for total coliforms and E. coli.

<table>
<thead>
<tr>
<th>Stage of assessment</th>
<th>(% ) Percentage of compliance by technology</th>
<th>p-value between technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ceramic filters</td>
<td>PUR</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before treatment</td>
<td>16.87</td>
<td>40</td>
</tr>
<tr>
<td>After treatment</td>
<td>84.43</td>
<td>54</td>
</tr>
<tr>
<td>Increase</td>
<td>67.76</td>
<td>14</td>
</tr>
<tr>
<td>Total coliforms</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>Before treatment</td>
<td>22.23</td>
<td>0</td>
</tr>
<tr>
<td>After treatment</td>
<td>22.23</td>
<td>0</td>
</tr>
</tbody>
</table>

E. coli < 1 cfu/100 ml (WHO, 2008); for total coliforms: < 10 cfu/100ml (Sphere project, 2004). Letters in superscript show the relationship between technologies, similar letters denote no significant difference, while different letters denote a significant difference.

Robustness

Figure 3 shows that the highest mean percentage reduction and mean log reduction in E. coli concentrations of the samples from unimproved water sources, were: 100% (log_{10} > 3.86) by ceramic filters, 100% (log_{10} > 1.78) by Aquatab, 100% (log_{10} > 1.80) by PUR and 86.82% (log_{10} 0.88) by Waterguard. There was no significant difference between the technologies p=0.05 (Table 2). None of the technologies showed a significant difference in performance between improved and unimproved drinking water sources.
Performance of each household water treatment technology against sector standards

Aquatab achieved neither the highly protective (log reduction ≥ 4) or protective (≥ 2) levels as classified by WHO (2011) in its standards for assessing the performance of HWT technologies.

Similarly, PUR’s performance using the observed log reduction values was below the LRVb for PUR of log 7. Waterguard did not attain its expected LRVb of log 3 for either total coliforms or E. coli during any of the assessment.

Ceramic filters achieved an E. coli concentration reduction which exceeded the LRVb of log 2 when used to treat unimproved water sources, once out of the three assessments for E. coli.

Table 3 Summary of performance of HWTS technologies in three assessments (E. coli indicator)

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Technologies’ Performance (Ranking)</th>
<th>p-value between technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log reduction in unimproved sources</td>
<td>Ceramic filters</td>
<td>PUR</td>
</tr>
<tr>
<td>Log reduction in improved sources</td>
<td>0.16 (4th)</td>
<td>0.94 (3rd)</td>
</tr>
<tr>
<td>Log reduction in combined sources</td>
<td>0.035 (4th)</td>
<td>0.78 (2nd)</td>
</tr>
<tr>
<td>Number of times reduction reached LRVb value in treatment of unimproved, improved and combined sources</td>
<td>1 out of 8 (3rd)</td>
<td>2 out of 8 (2nd)</td>
</tr>
</tbody>
</table>

Discussion

Robustness

Robustness is an important criterion for assessing the effectiveness of household water treatment technologies because it indicates how well a method can improve the quality of water irrespective of its turbidity or organic load (Sobsey et al., 2008).

Given that rural communities in Kenya and elsewhere commonly depend on polluted water sources of high turbidity and organic load, it is important that HWT technologies be robust enough to treat such water sources effectively. This was also important in this study as more than two-thirds of the households depended on surface water sources which had a mean turbidity of 210 NTU.

Though there was no statistical significance to the difference in performance of the technologies when used to treat improved and unimproved water sources, Aquatab performed better when used to treat water from improved sources than from unimproved. Its mean log reduction in E. coli concentrations was three times higher in improved sources compared with unimproved sources. This reduction in efficacy is consistent with the report by Clasen and Edmonson (2005) that the mean log reduction of Aquatab decreased from 4 when Aquatab was used to treat water of low turbidity to between 1.8 and 2.8 when highly turbid water was treated.

In contrast, PUR performed better with unimproved sources than improved sources, with log reductions in E. coli concentrations being three times higher in unimproved water sources compared with improved. This is consistent with the product’s objective of turbidity reduction and disinfection. It is also consistent with the report by Crump et al. (2004) that the flocculant-disinfectant assessed was the only HTW product out of those assessed (Waterguard, alum and PUR) that reduced E. coli concentrations below 1 cfu/100 ml in a high turbidity setting.

The study findings suggest that Waterguard performed better when used to treat improved water sources. This is consistent with Crump et al. (2004) finding in Western Kenya that sodium hypochlorite reduced E. coli concentrations to < 1 cfu/100 ml in water sources with low (< 10 NTU) and medium turbidity (10–100 NTU), but did not do so when used to treat highly turbid water (> 100 NTU).

Figure 3 Performance of HWT technologies in unimproved water sources
With regard to ceramic filters, the observed changes in mean *E. coli* concentrations after household treatment of water sources was not consistent enough to make inferences about the effect of turbidity on the effectiveness of ceramic filters.

For example, in one of the assessments, the mean *E. coli* concentration increased after treatment of *improved* water sources, resulting in a lower mean log reduction (0.16) in *improved* compared to *unimproved* sources (1.6). This increase in bacterial load in treated *improved* water sources, is consistent with the report by Bielefeldt *et al.* (2009) that they observed bacterial deposits into previously clean water from the filter, after it has been used to treat batches of water with high bacterial loads, and emphasizes the importance of integrating hygiene education with HWTS programs.

**Microbial efficacy**

One to two years after external support had ceased, none of the four HWT methods was consistent in their ability to improve the quality of the treated water to the accepted drinking water standards for either *E. coli* or total coliforms when consistency was taken as the ability to meet the standards in a minimum of two of the three assessments.

In another study also conducted in Western Kenya, Albert *et al.* (2010) found that 51%, 39% and 33% of water samples treated with Waterguard, ceramic filters and PUR respectively complied with the WHO drinking water standard for *E. coli*. This study found that 46.7%, 84.4%, 54% and 81.85% of samples complied with the standards for *E. coli* in drinking water after treatment with Waterguard, ceramic filters, PUR and Aquatab respectively.

Given that the mean log reduction of the four HWT methods assessed ranged from 0.16–2.3 when used to treat *improved* water sources and 0.44–2.0 when used to treat *unimproved* water sources, none of the assessed technologies can be classified as providing a highly protective or even protective effect in the circumstances in which they were assessed during this study.

Sector experts have questioned whether the poor quality of treated water obtained with some HWT methods is due to poor HWT effectiveness, or poor user compliance and other behavioural factors (Hunter, 2009 and McLaughlin *et al.*., 2009).

This study’s findings indicate that one of the reasons for the poor water quality observed is the disconnection between the household’s HWT technology choice and what is appropriate for the drinking water sources they use. For example, in spite of the high turbidity of the drinking water sources used in these communities, the KAP study show that very few households use HWT methods designed to reduce turbidity. For instance, PUR was used by 9.3% of households in the intervention group and no household in the control group; while ceramic filters were used by only 23.26% in the IG and no household in the CG.

This is consistent with Albert *et al.* (2010) who observed that contrary to expectations, households which used surface water sources did not use PUR more often than Waterguard, even though Waterguard has been shown to be ineffective in highly turbid waters (Crump *et al.*, 2004 and Lantagne, 2006).

The high-risk study setting is another factor that may have contributed to the findings of lower effectiveness of the HWT technologies compared to the level of efficacy observed in laboratory and field studies. Poor water, sanitation and hygiene conditions were prevalent, where only one in two households used *improved* water sources and only one in twelve used *improved* sanitation.

The unhygienic setting was compounded by poor knowledge, attitudes and practices and although a majority of the households (91.4%) treated water on the day of the assessment, less than half the users of the four HWT methods were familiar with the three most critical steps for effective use of the HWT technologies. This reduced the likelihood of their achieving the expected baseline log reductions, particularly in the light of the observed poor water quality used by the study communities.

In light of the above, it is not surprising that the technologies did not consistently achieve the baseline reduction value, which is the minimum reduction in microbial concentration expected in actual field practice when HWT is done by relatively unskilled persons who apply the treatment to waters of varying quality (Sobeys *et al.*, 2008; WHO, 2008).

Given that the efficacy of these water treatment methods have been proven in some laboratory and short-tern field trials, it is reasonable to conclude that user behavior affected the performance of the HWT technologies in the real-world context of this study.
Lessons Learned
The findings of this study illustrate the relationship between poor user behaviour and performance of household water treatment technologies post-implementation. The study’s identification of KAP practices and aspects of the HWT technologies that cause users to perceive them as low or high value products will help to improve their effectiveness and impact on health in typical-use situations. The main lessons learnt are that:

1) User behaviour affects the performance of HWT technologies.
2) Majority of the respondents did not know the critical steps for effective household water treatment use. Most of the respondents also did not know how to select the household water treatment method that most suited their type of water source so as to meet their three most frequently mentioned expectations of safe drinking water: visual clarity, absence of germs, and the taste.
3) Provision of improved water sources is the first step towards protecting the health of users, and enforcement of adherence by practitioners to the stipulated standards for development of these water sources.
4) Waterguard was less effective when used to treat highly turbid water sources.

Next Steps
Based on the findings of this study, the following actions are recommended:
1) Integration of HWT promotion with sanitation and hygiene promotion with an increased focus on user-awareness of contamination routes and barriers, the role of household water treatment in disease prevention, under-five sanitation practices, the importance of hand-washing with soap after faecal contact and appropriate water storage practices.
2) Education of communities on the critical steps for effective household water treatment use, and selection of household water treatment methods that will meet the three most frequently mentioned expectations of safe drinking water: visual clarity, absence of germs, and the taste of drinking water.
3) Short-term measures should be implemented to enable users select appropriate HWT technologies to treat highly turbid water sources and long-term measures to develop simple tools to assist households determine the turbidity levels of their water sources.

References


References


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