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Consistency of Use and Effectiveness of Household Water Treatment among Indian Households Claiming to Treat Their Water

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Abstract. Household water treatment (HWT) can improve drinking water quality and prevent disease if used correctly and consistently by populations at risk. Current international monitoring estimates by the Joint Monitoring Programme for water and sanitation suggest that at least 1.1 billion people practice HWT. These estimates, however, are based on surveys that may overstate the level of consistent use and do not address microbial effectiveness. We sought to assess how HWT is practiced among households identified as HWT users according to these monitoring standards. After a baseline survey (urban: 189 households, rural: 210 households) to identify HWT users, 83 urban and 90 rural households were followed up for 6 weeks. Consistency of reported HWT practices was high in both urban (100%) and rural (93.3%) settings, as was availability of treated water (based on self-report) in all three sampling points (urban: 98.8%, rural: 76.0%). Nevertheless, only 13.7% of urban and 25.8% of rural households identified at baseline as users of adequate HWT had water free of thermotolerant coliforms at all three water sampling points. Our findings raise questions about the value of the data gathered through the international monitoring of HWT as predictors of water quality in the home, as well as questioning the ability of HWT, as actually practiced by vulnerable populations, to reduce exposure to waterborne diseases.

INTRODUCTION

Inadequate access to drinking water remains a major cause of morbidity and mortality, especially among children under 5 years of age in low- and middle-income countries (LMICs). Recent estimates for the Global Burden of Disease 2013 study indicate that in 2013, 1.2 million premature deaths and 75.1 million disability-adjusted life years globally were due to unsafe water sources.[1]

Household water treatment (HWT), including boiling, filtering, chlorination, and solar disinfection, combined with safe storage, has been shown to significantly improve the microbial quality of drinking water[2] and reduce the risk of diarrheal diseases among the millions relying on unimproved water sources,[3] and among those that rely on improved water sources that are nevertheless contaminated, an estimated 1.8 billion people.[4]

Evidence from various systematic reviews, some including meta-analysis, have shown a protective effect of HWT against diarrhea in children under 5 years of age.[5–8] Although some have highlighted as a weakness that the bulk of the evidence is derived from unblinded trials of HWT interventions that use subjective outcomes (self-reported diarrhea) and are thus subject to differential outcome reporting bias,[9] the World Health Organization (WHO) promotes the use of HWT within a comprehensive 7-point plan to control diarrheal diseases in LMICs.[10]

Commencing in 2005, the WHO/United Nations Children's Fund Joint Monitoring Programme for Water and Sanitation (JMP) started to gather data on HWT practices through their routine monitoring mechanisms. The JMP recommended the inclusion of two core questions on whether and how HWT is practiced, to their nationally representative household surveys: 1) do you treat your water in any way to make it safer to drink, and if the response is affirmative, 2) what do you usually do to the water to make it safer to drink.[11] No questions assessing the safe storage of the water once treated was recommended.

The objectives of these two questions were to determine the global prevalence of this practice, and by classifying HWT as adequate (if the method has been shown to be microbiologically effective, i.e., boiling, filtering, chlorination, and solar disinfection) or inadequate (if not, i.e., strain through a cloth and stand and settle), to assess whether these questions could act as proxy indicators of water quality in the home.[11,12] Analysis of these data show that an estimated 1.1 billion people among 67 LMICs,[13] and over 1.8 billion people if data from China are included, are practitioners of HWT.[14]

While relying on such methodology may be the most practical and cost-effective means of gathering such data at the national and regional level, there are concerns that this survey-based, self-reported data might not provide reliable and valid data for public health and policy purposes.[15–17] Overreporting of water, sanitation, and hygiene (WASH) practices, especially HWT, is a common phenomenon.[18–20] Furthermore, multiple quantitative microbial risk assessment models have shown that not only the effectiveness but also the consistency of HWT use (also referred to in the literature as adherence or compliance) are key aspects to ensure the protective effects of HWT.[21–23] It thus remains unclear if the two core JMP questions on HWT use can capture the complexity of this behavior and act as a reliable proxy for water quality in the home.

With funding and support from the JMP, a series of case studies were conducted in both urban and rural settings in India, Peru, and Zambia with the aim to 1) document HWT practices among populations self-reporting to be practitioners of HWT according to current JMP monitoring procedures, 2) to characterize the microbial quality of drinking water among self-reported HWT users, and 3) to assess to what extent the JMP core questions capture these aspects of HWT.

We previously reported results from Peru and Zambia.[24,25] Herein, we report results from India, a lower-middle-income

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country where, according to JMP figures, in 2005–2006, 11.9% of households relied on unimproved water sources and 34.4% reported the use of HWT, mainly by boiling (10.4%) or straining water through a cloth (16.6%).[26]

MATERIALS AND METHODS

Study design. The primary objectives of this study were to 1) gain an understanding of the actual HWT practices of those households identified under current JMP monitoring procedures as HWT users and 2) assess the implications of any discrepancies on the current monitoring strategy. For this purpose, qualitative and quantitative methods were used. These were used to investigate and cross-check the relationship between reported and actual HWT behaviors.

A baseline survey was undertaken to identify HWT self-reporters and obtain information on the demographic, socioeconomic, and WASH practices of the participating households. The survey closely aligned with the Demographic and Health Surveys (DHSs) and the Multiple Indicator Cluster Surveys (MIC), which the JMP relies on for monitoring purposes. Using a random number table, a random sample of 110 households self-reporting HWT (i.e., responded affirmatively to the JMP core question on HWT—"Do you treat your water in any way to make it safer to drink?") were selected for follow-up. This consisted of 1) either a second survey (hereinafter, the "HWT practices survey") or structured home observations followed by an in-depth interview (IDI), and 2) three rounds of spot-check observations and water sampling (Figure 1). The first of these took place at the end of the HWT practices survey or IDI, and the remainder took place at approximately 1-week intervals at unannounced visits.

Study setting. The study took place between July and September 2010, in the state of Maharashtra. This coincided with the monsoon season. The urban substudy was conducted in the city Navghar-Manikpur, in Thane District, approximately 50 km north of Mumbai city. The city, with a population of 116,700, is sustained mainly by commerce and industry. The rural substudy was conducted in three neighboring villages in Shirsad, Thane District, on the skirts of the Nashik-Mumbai highway, approximately 70 km of Mumbai. Subsistence farming mainly supported these communities. In the rural setting, all households in the three villages were approached for participation. In the urban setting, due to the unavailability of a sampling frame, the city was divided into two broad areas (west and east), the former comprising mainly residential areas and the latter industrial areas. The study was restricted to the west area and this was further subdivided into four sectors of approximately

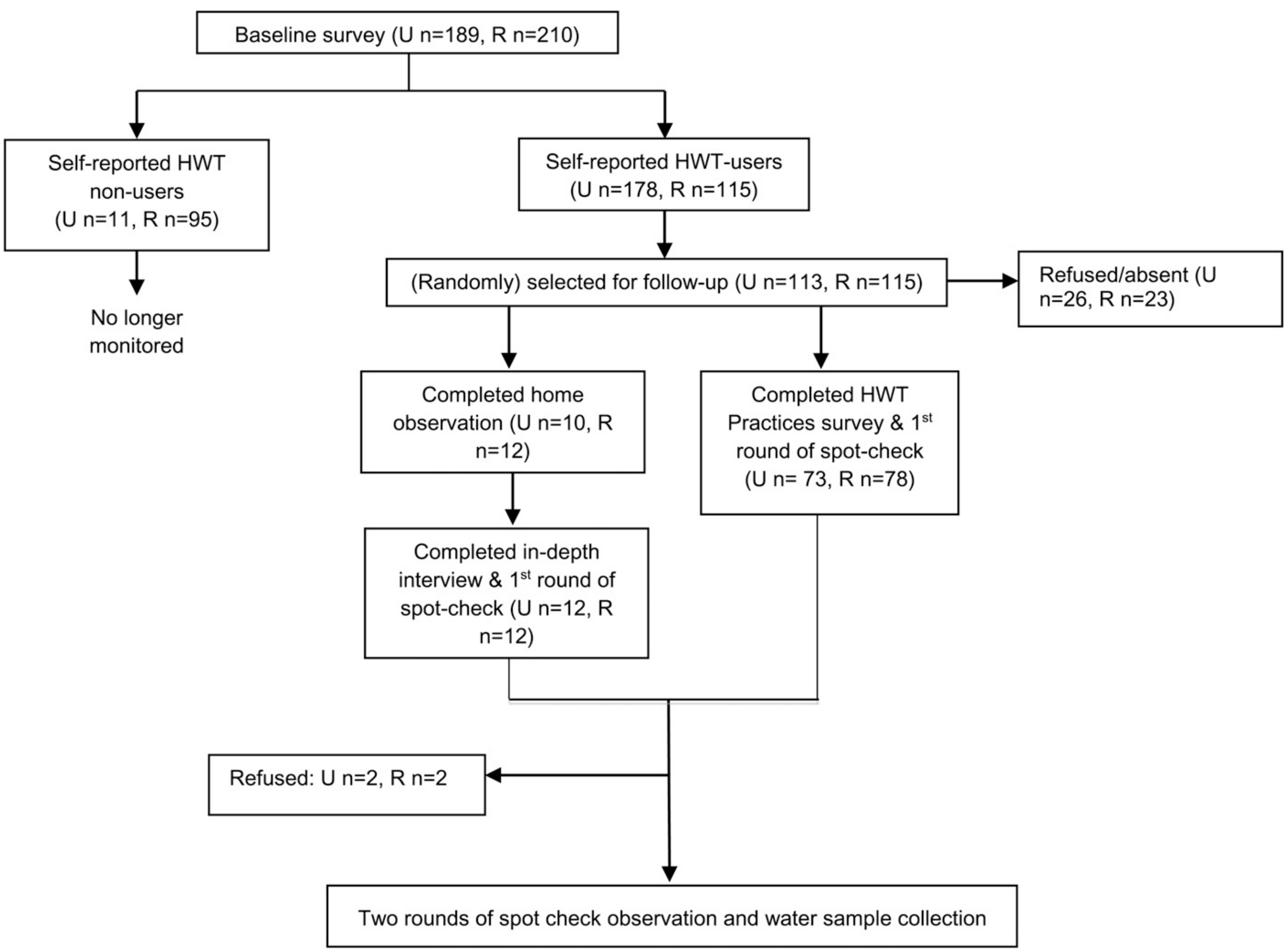

FIGURE 1. Schematic representation of the study design (U = urban, R = rural).

similar size. Systematic sampling, by selecting every 25th household, was used. In both settings, study participants were recruited through door-to-door visits. Further details on participant eligibility have been described previously.[24,25]

Sample size. Sample size calculations were based on precision rather than power. Aiming for a precision of ±10%, a minimum of 80 households reporting HWT use was required for the study. Taking into account a 15% refusal rate for participation and a further 15% dropout rate, 110 households needed to be recruited at baseline. Using the India DHS 2005–2006 HWT use prevalence figures for the state of Maharashtra (urban [U]: 74.0%, rural [R]: 63.2%), 158 and 186 households in the urban and rural areas, respectively, had to be approached to identify the required number of HWT users.

Home observations and IDIs. Structured home observations were undertaken with the dual aim of 1) assessing whether, and how often, HWT was performed to verify the self-reported status of households, and 2) to assess whether treated water was consumed exclusively or supplemented with untreated water, and if so, understand the rationale for this. Approximately 15% of households reporting HWT were purposely selected to complete three consecutive days of structured observations in their home followed by an IDI. However, due to a high refusal rate, a further 17 households had to be approached to reach the target number of households. Only households with at least one child under 5 years of age were invited; furthermore, households were selected with the aim of maximizing the number of HWT methods observed. While we anticipated completing 4–6 hours of observation daily, starting early in the morning to capture most housekeeping activities, including the period when HWT was reportedly most frequently performed, households, especially in the urban substudy, were reluctant to allow the observations to commence prior to 9:00 AM. To reduce bias among participants, observations were introduced with the aim to understand child caring practices in general, drawing no attention to HWT, water quality, or water practices in general. At the end of the study, all participants were informed about the true nature of the study, received the microbiological results of their water samples, and were informed of ways to improve the quality of their drinking water at home. While we had requested young, female observers, the data collection agency was reluctant to provide these on the basis of safety of their female workers, and male observers undertook all but two sets of observations. It is thus highly likely that the use of male observers increased subject reactivity and so the results presented here should be taken with caution. The IDIs were undertaken with the female head of the household or main caregiver at the end of the 3rd day of observation. A topic guide, closely following the HWT practices survey (see the Reported HWTS practices survey section) but allowing more flexibility and probing, was used. All IDIs were undertaken in Marathi, were recorded, transcribed, and translated by the observers. Participants received a coloring booklet and a set of coloring pens for their children at the end of the IDI.

Reported HWTS practices survey. The remaining households completed a detailed survey on HWT practices. The aims of this survey were to 1) assess the reliability of the core JMP question by administering the core question on HWT use a second time, and 2) to gain further insight on HWT practices, with a special focus on consistent use.

Observational spot-check visits. At the end of the HWT practices survey or IDI, and at two consecutive occasions at approximately 1-week intervals, all households completed an observational spot-check. During this visit, participants were asked to identify all drinking water containers in the households. The aim of these observational spot-check visits was to obtain objective indicators of actual HWT use. Data were gathered on 1) availability of treated water at the time of the visit (based on self-report), 2) ability to show the materials used to perform HWT, 3) objective proxy indicators of HWT use, such as free chlorine residuals for those reporting chlorination, water in the filter for those reporting filtration, and time of boiling and temperature of boiled water for those reporting boiling.

Water quality. At each observational spot-check visit, a sample of drinking water was obtained. Participants were asked "If you or someone in this household wanted a drink of water right now, what water would you drink from?" In households with at least one child < 5 years of age, fieldworkers were instructed to ask in reference to the child. Thereafter, participants were asked to identify the source from which the water was collected, and immediately after a paired source sample was collected. All water samples were collected in sterile 110-mL Whirl-Pak (Nasco Corp., Fort Atkinson, WI). Samples were placed on ice, transported to a laboratory, and processed within 4 hours of collection to assess levels of thermotolerant coliforms (TTC). Microbiological assessment was performed using the membrane filtration method[27] using a DelAgua field incubator (Robens Institute, University of Surrey, Guilford, Surrey, United Kingdom). For quality assurance, a negative control and two duplicates were undertaken in each batch of analysis.

Data analysis. To assess the consistency of reporting HWT practices among those originally identified as HWT users according to current monitoring procedures, we assessed the concordance of HWT reporting at both questioning events (at baseline and during the HWT practices survey or IDI). To further assess the level of consistent use, we calculated the number of visits in which a household reported to have treated water. Additionally, we cross-checked the availability of treated water at the time of the unannounced visit with self-reports of daily HWT use and exclusive drinking of treated water.

For the home observations, simple descriptive analysis, involving counting of relevant events (such as water drinking events or use of HWT) and descriptions of HWT events was undertaken.

The distribution of TTC counts was zero inflated and right-skewed; for this reason we present medians, the interquartile range, and Williams mean as measures of central tendency. The Williams mean is calculated by adding 1 to all the data values, then taking the geometric mean, then subtracting 1 again. To assess if the drinking water of self-reported users of adequate HWT methods identified at baseline was of higher microbial quality than their source water, TTC counts were $\log_{10}$ transformed after imputing a value of 1 to the zero counts and the difference of the paired source-drinking water samples was calculated for each of the three rounds of follow-up. Log_{10} transformation of TTC counts did not achieve normality of the data. For this reason, a nonparametric test (i.e., Wilcoxon signed-rank test) was applied to analyze each individual round of water quality data.

To assess the overall difference in water quality across all three rounds of data collection, we used negative binomial regression.[28] We used raw mean counts of TTC, with outcomes expressed as risk ratios (RRs), estimating the change in the relative mean number of events between categories.[29,30] The analysis used robust variance estimation to adjust for clustering at the household level. Additionally, we conducted the same analysis, using random effects logistic regression to account for the clustering at the household level and defined microbial quality of the drinking water as detection of TTC contamination (≥ 1 colony-forming units [CFU]/100 mL) versus no detection of TTC contamination (< 1 CFU/100 mL).

To assess the water handling determinants (such as type and covering of storage container, method of serving water, and reported time since treatment) of microbial quality of the drinking water (defined as detection of TTC contamination versus no detection of TTC contamination), bivariate and multivariate analyses were conducted. We used random effects logistic regression to account for the clustering at the household level. Final model selection using multivariate analysis was based on the inclusion of variables with P values of ≤ 0.10 in bivariate analysis. Analysis was not conducted on the continuous scale of TTC as the models were found to be unstable. All statistical analyses were conducted using STATA version 10 (Stata Corp., College Station, TX).

Ethics. The study was reviewed and approved by the Ethics Committee of the London School and Hygiene and Tropical Medicine (Reference No. 5696 dated April 13, 2010) and by the Institutional Review Board of Hindustan Unilever Limited. Informed written consent to participate in the research was obtained from the head of the household or spouse of each participating household.

RESULTS

Baseline characteristics. A total of 189 and 210 households completed the baseline survey in the urban and rural substudies, respectively (Supplemental Table 1). Households were headed by a male member in over 85% of cases in both settings. Educational attainment was high in the urban substudy with over 80% of heads of household attending higher education; in the rural setting, only 30% of heads had higher education, whereas 20% had no education. In the urban substudy, households mainly relied on piped water into the dwelling (89.4%) for drinking purposes, whereas rural participants relied on piped water into the dwelling (21.0%), into the yard or plot (19.5%), or more commonly, on public standpipes (56.7%). Use of improved sanitation was almost universal in the urban substudy (98.4%), whereas it was less prevalent in the rural substudy (51.9%), 48.1% had no sanitation facilities. Sharing of these facilities was rare in the urban substudy (4.3%), but commonplace for those using a toilet facility in the rural substudy (27.5%).

Almost all urban households (94.2%, 95% confidence interval [CI] = 90.8–97.5) reported affirmatively to the JMP core question on HWT use. This figure was higher than the India DHS figure for urban areas for the state of Maharashtra (80.1%, 95% CI = 79.1–81.1). Boiling (56.6%, 95% CI = 49.5–63.7) and the use of water filters (40.7%, 95% CI = 33.7–47.8) were the most common methods reported. In the rural substudy, approximately half of the participating households (54.8%, 95% CI = 48.0–61.5) reported to treat their drinking water. Boiling was the most common method (35.7%, 95% CI = 29.2–42.2), followed by straining water through a cloth (16.2%, 95% CI = 11.2–21.2). The use of water filters was much less common (9.0%, 95% CI = 5.1–13.0).

HWTS practices survey. Overall, 73 and 78 households completed the HWT practices survey in the urban and rural substudies, respectively (Table 1). Storage of water was commonplace in both substudies; the use of open-mouth containers was equally common.

At this second questioning event, all urban and 93.6% of rural households, respectively, provided an affirmative response to the JMP core question on HWT use. Consistent with baseline data, boiling and the use of water filters were the most common methods reported in the urban substudy, whereas boiling and straining through a cloth were most common in the rural context. A substantial proportion of households reported more than one method of treatment (U: 20.5%, R: 15.1%).

The majority of households in the urban substudy reported treating their water year-around, whereas three-quarters of rural households reported to do so. The majority of households in both settings reported to treat their drinking water on a daily basis (U: 94.5%, R: 86.3%).

Similarly, almost all households in both settings reported that all family members would consume the treated water (U: 98.6%, R: 87.7%). Reported supplementation of treated water with untreated water was uncommon in the urban substudy (4.1%), but more common in the rural setting (21.9%).

Home observations. A total of 10 and 11 households were observed for a mean of 4.7 and 11.2 hours in the urban and rural substudies over a 3-day period (Supplemental Table 2). As a result of 1) the inability to commence observation prior to 9:00 AM, and 2) the limited hours of observation, only a total of 44 water drinking events were observed in the urban substudy. Twice the number of water drinking events was observed in the rural setting. However, only one HWT event in the urban substudy and three events in the rural substudy were observed. This made the classification of water drinking events as treated or untreated water extremely difficult and a substantial proportion of events were thus unclassifiable (U: 70.0%, R: 51.8%). In only two rural households, both of which reported to boil their drinking water daily, it was possible to classify drinking water events as untreated water. In these two cases, 40.0–41.7% of the water consumed was untreated.

In the urban substudy, of the three households that reported the use of a water filter at baseline, all three households were observed to have a working filter and the filter had water in all observation days. Additionally, of the 15 drinking events observed in these households, 12 were confirmed filtered water. A similar picture was observed in the rural substudy among the four households that had reported filtering their drinking water at baseline. In these households, all 53 water drinking events were confirmed to be filtered water.

TABLE 1
Summary of reported HWT practices as reported during the HWT practices survey

Characteristic	Urban		Rural	
	n	%	*n*	%
No. of households	73	–	78	–
Perceived water safety of drinking water source				
Always safe	22	30.1	20	25.6
Usually safe	46	63.0	43	55.1
Sometimes safe	4	5.5	14	18.0
Other	1	1.4	1	1.3
Water handling practices				
Store drinking water at home	73	100.0	78	100.0
Percentage of households with > 1 type of storage container	23	31.5	6	7.7
Type of storage vessel*				
Clay pot (wide opening)	22	30.1	7	9.0
Metal container (wide opening)	40	54.8	67	85.9
Bottles	15	20.5	8	10.3
Water filter	14	19.2	9	11.5
Other	1	1.4	–	–
Report covering drinking container	57	98.3	70	100.0
Access drinking water (only for wide vessels)				
Pour from container	19	26.0	13	16.7
Dip glass/use ladle	27	37.0	65	83.3
Use tap in container	10	13.7	0	0.0
Other	17	23.3	0	0.0
HWT practices				
Reported HWT use	73	100.0	73	93.6
Reported method†				
Boil	39	53.4	47	64.4
Use a water filter	36	49.3	12	16.4
Strain through a cloth	9	12.3	25	34.3
Use alum	5	6.8	0	0.0
Multiple methods reported	15	20.5	11	15.1
Use treated water for other purposes	15	20.5	20	25.6
HWT performed year around	65	89.0	54	74.0
Reported frequency of HWT use				
Daily	69	94.5	63	86.3
Regularly but not daily	3	4.1	6	8.2
Rarely	1	1.4	4	5.5
All household members consume the treated water	72	98.6	64	87.7
Respondent reports drinking untreated water in the home (supplements)	3	4.1	16	21.9

HWT = household water treatment.
* Respondents may report multiple types of container, so the sum of containers may exceed 100%.
† Respondents may report multiple methods of HWT, so the sum may exceed 100%.

It was further observed that in both settings, all but one drinking water event by children under 5 years were drinks provided by an adult to the child. This suggests that at least in this setting water consumed by children can be, to a large extent, controlled by adults.

In-depth interviews. Overall, 12 households completed the IDI in the urban and rural substudies. In the urban setting, nine households relied on piped water into the premise, whereas the remainder either used piped water to the yard or plot or public standpipes. Of these households, nine were satisfied with their water as it would be delivered directly to their homes and it was acceptable in terms of taste, smell, color, and safety. The remaining three households reported to be unsatisfied, as water would at times appear clean and safe while at other times it would not. Interestingly, while those satisfied agreed that their water was safe and clean, they reported to treat their drinking water for "extra" safety. In the rural setting, 10 households relied on piped water to the premise or public standpipes, whereas the remaining two relied on private wells. In this setting, there was a general feeling of mistrust with regard to the quality of the drinking water.

In the urban substudy, all households were consistent with their reported HWT status at baseline, although four households reported different number of methods between questioning events. In the rural setting, all but one household, which recently had switched to bottled water, reported practicing HWT. Of these, three reported different methods from that previously reported at baseline.

All 12 urban and 11 rural households reported health as the main reason for performing HWT. All households reported that by performing HWT they could prevent diarrheal diseases, no other illnesses were mentioned in the urban setting, but two rural households mentioned jaundice and malaria. Four urban households made specific reference to microbes in water. In addition, four rural households reported other reasons for practicing HWT; these were 1) cost-savings from reduced medical fees, and 2) aesthetic improvements in water.

Treated water was noted to be as beneficial for adults as for children in both settings. All but one urban and one rural household reported that treated water was as important for children as for adults and reported that there was no age at which children no longer needed treated water.

All urban and rural households were aware of other methods of HWT other than the ones being currently practiced. In general, participants were satisfied with their choice of HWT in terms of safety, convenience, time, and cost. Among the urban boilers (*N* = 4) and two of the rural boilers, households were not aware of the direct costs of boiling, as they had never calculated how much fuel would be used for this task specifically, as opposed to cooking. However, in both settings, all households reported that the money spent was worthwhile as otherwise this would be spent on medical fees. In the rural setting, the high-end water filter users (*N* = 4) reported using this option because they felt that this was the most reliable option and because they had lost faith in other methods. Two of these households reported switching from boiling after members of their family had fallen ill and they had lost faith in boiling.

Consistency of HWT use. Consistency of HWT use in both substudies was high, all households in the urban setting and 93.3% on the rural setting reported to be HWT practitioners at both questioning events (Table 2). Nonetheless, a substantial proportion of participants reported a different HWT method at both of these events (U: 32.9%, R: 34.5%). Over the entire follow-up period, 98.8% of urban and 74.7% of rural households reported to treat water at both questioning events and reported to have treated water at all three sampling events; however, over half of households reported a different HWT method in at least one of these events (U: 55.6%, R: 52.9%).

Of the households that reported using a water filter at baseline (U: *N* = 36, R: *N* = 16), 80.6% of urban and 93.8% of rural households were able to show the filter upon request. Cross-checking the status of boiling or straining through a cloth proved to be challenging as the pots used for boiling the water and the cloth used for straining the water were used for other purposes too.

Among reported daily HWT users that had water available on all collection visits in the urban setting (*N* = 77), all participants reported to have treated water at all three sampling events. Likewise, all households reporting not to supplement their drinking water with untreated water, reported to have treated water at all three sampling visits. In the rural substudy, 86.7% of reported daily HWT user and 92.6% of nonsupplementers reported to have treated water at all three sampling visits.

Water quality. The microbial quality of both source and drinking water of rural households identified as users of adequate methods of HWT at baseline was of higher quality than that of its urban counterparts (Table 3, Figure 2). Overall, 74.9% (95% CI = 68.9–80.9) of source water samples and 59.9% (95% CI = 53.1–66.7) of drinking water samples were free of TTC in the rural context as opposed to 36.6% (95% CI = 30.3–42.9) of source and 36.1% (95% CI = 29.8–42.2) of drinking water samples in the urban context. However, paired analysis of source and drinking water samples showed that while in the urban context drinking water was of no better quality than source water, in the rural setting, the microbial quality of drinking water was significantly worse than source water (Table 3). In the urban context, paired water samples showed a mean $\log_{10}$ difference of −0.21 to 0.37 across the three follow-up visits, whereas in the rural setting, mean $\log_{10}$ differences of −0.35 to −0.46 were observed across the three follow-ups, indicating consistently higher contamination of drinking water. Analysis across all rounds of data, showed similar results (U: RR = 0.82, $P = 0.1$, $N = 448$, R: RR = 4.12, $P < 0.001$, $N = 405$). Analysis in the binary scale (no < 1 CFU/100 mL versus ≥ 1 CFU/100 mL) showed similar results.

Over the course of the entire follow-up, of those household that reported adequate methods of HWT at baseline, only 13.7% of urban and 25.8% of rural households had water free of TTC at all three water sampling points.

Differences were noted between the adequate methods of HWT reported at baseline and the quality of the drinking water throughout the study (Supplemental Figure 1). In the urban setting, households that reported the use of a water filter at baseline were significantly more likely to have water of higher quality than their source water (RR = 0.55, $P = 0.02$, $N = 212$). Analysis in the binary scale showed a similar, but nonsignificant trend (odds ratio = 0.66, $P = 0.18$). By contrasts, households that reported boiling at baseline had water of no better quality than their source water (RR = 0.95, $P = 0.65$, $N = 310$). Analysis in the binary scale showed similar results. Nevertheless, only 24.4% of households that self-reported filtering at baseline had water free of TTC at all

TABLE 2

Consistency of HWT use among households that self-reported performing HWT at baseline in the urban and rural communities

Characteristic	Urban		Rural	
	n	%	*n*	%
Consistent reporting of HWT use in the baseline and HWT practices survey/IDI*	85	100	84	93.3
Consistent reporting of HWT method among those reporting use in both the baseline and HWT practices survey/IDI†	57	67.1	55	65.5
Consistent reporting of HWT use in all five HWT reporting events‡	80	98.8	56	74.7
Consistent reporting of HWT methods in all five HWT reporting events§	36	44.4	33	47.1
Availability of treated water in all three sampling visits (based on self-report)¶	81	98.8	57	76.0
Subgroup analysis				
Households able to show water filter among those that reported filtering their water at baseline	29	80.6	15	93.8
Claimed to have treated water at all three collection points				
Among reported daily HWT use‖	77	100	52	86.7
Among reported nonsupplementers**	65	100	50	92.6

HWT = household water treatment; IDI = in-depth interview.
* Among households that completed both visits (U: *N* = 85, R: *N* = 90).
† Among households that reported HWT at both questioning events (U: *N* = 85, R: *N* = 84).
‡ Among households that completed all four visits and had water available at all three points (U: *N* = 81, R: *N* = 75).
§ Among households that had data at all five questioning events (U: *N* = 81, R: *N* = 70).
¶Among households that had data at all five questioning events (U: *N* = 82, R: *N* = 75).
‖Among households that had water at all three points and reported daily HWT use (U: *N* = 77, R: *N* = 60).
** Among households that had water at all three points and reported to be nonsupplementers (U: *N* = 65, R: *N* = 54).

TABLE 3

Summary statistics of the microbial quality of samples of source and drinking water collected at each follow-up visit among those households identified at baseline as users of adequate HWT methods

	Source							Drinking							Paired samples			
	n	Median	IQR	AM	95% CI	WM	95% CI	*n*	Median	IQR	AM	95% CI	WM	95% CI	*n*	Mean log_{10} difference	95% CI	Wilcoxon signed-rank test (*P* value)
Urban																		
Visit 1	78	86	2 to 1,000	343.6	248.3 to 428.8	49.5	26.6 to 91.4	78	14	0 to 256	255.9	165.3 to 346.4	20.5	10.6 to 38.8	78	0.37	0.07 to 0.67	0.16
Visit 2	74	0	1 to 100	192.7	106.1 to 279.2	6.6	3.0 to 13.4	74	2	0 to 192	204.6	117.5 to 291.8	11.2	5.5 to 21.9	74	−0.21	−0.54 to 0.13	0.24
Visit 3	75	22	0 to 648	303.7	210.0 to 397.4	25.0	12.3 to 49.9	75	25	0 to 208	210.4	129.7 to 291.1	20.1	0.5 to 37.5	75	0.09	−0.21 to 0.39	0.50
Rural																		
Visit 1	69	0	0 to 2	29.6	5.6 to 53.6	1.7	0.8 to 3.1	67	0	0 to 37	138.7	59.5 to 217.8	4.8	2.2 to 9.8	67	−0.35	−0.62 to −0.07	0.05
Visit 2	67	0	0 to 0	5.1	1.0 to 9.3	0.6	0.2 to 1.2	67	0	0 to 18	48.2	18.4 to 78.0	3.5	1.7 to 6.6	67	−0.44	−0.68 to −0.20	< 0.001
Visit 3	67	0	0 to 0	37.2	3.5 to 70.9	1.2	0.4 to 2.4	68	0	0 to 96	109.8	56.6 to 163.0	5.1	2.2 to 10.4	67	−0.46	−0.76 to −0.15	< 0.01

AM = arithmetic mean; CI = confidence interval; HWT = household water treatment; IQR = interquartile range; WM = Williams mean.

three follow-ups (this ranged from 36.7% to 57.6% at individual follow-up visits). In the rural setting, a similar pattern was observed. Households that reported filtering at baseline had water of higher quality than their source water, although this was of borderline significance (RR = 0.21, *P* = 0.08, *N* = 90), whereas those that reported boiling had water of significantly worse quality than their source water (RR = 6.31, *P* < 0.001, *N* = 327). Analysis in the binary scale showed similar trends. Nonetheless, only half of households reporting the use of filters had water free of TTC at all three water sampling points (this ranged from 75.0% to 81.3% at individual collection points).

A similar picture was observed when we assessed the quality of the drinking water based on the reported HWT status at the time of sample collection as opposed to what was reported at baseline in response to the core JMP question on HWT. There was some evidence that the microbial quality of drinking water differed by reported method of treatment at time of sample collection (Supplemental Table 3). In both the urban and the rural context, boiled water samples were of lower microbial quality than the source water; this was particularly apparent in the rural context (urban: RR = 1.30, *P* = 0.05, *N* = 508; rural: RR = 7.09, *P* < 0.001, *N* = 530). Filtered water was moderately of better quality in the urban context (RR = 0.47, *P* = 0.01, *N* = 508). In the rural context, filtered water was not significantly better than source water (RR = 1.71, *P* = 0.43, *N* = 530); however, it maintained the high microbial quality of the source as opposed to the boiled samples (Supplemental Table 3).

Overall, 53.6% (95% CI = 44.2–63.0) and 75.5% (95% CI = 63.5–87.4) of reportedly filtered water in the urban and rural contexts, respectively, maintained the high quality of the source water or reduced the contamination level to < 1 CFU/100 mL. On the other hand, 21.2% (95% CI = 13.2–29.1) of urban and 47.5% (95% CI = 38.4–56.6) of rural reportedly boiled water samples met this criterion.

In the multivariate random effects logistic regression model for risk factors of detectable TTC, reported method of HWT and microbial quality of the source water were the only water-related factors associated with water quality in the urban setting (Supplemental Table 4). In the rural setting, both these factors, as well as reported time since treatment were associated with microbial quality of the drinking water (Supplemental Table 4). For the reportedly boiled water samples, in the urban setting, only the microbial quality of the source water was associated at the bivariate level; due to the small sample size, multivariate analysis was not conducted. In the rural setting, both reported time since treatment and quality of the source water were associated at the bivariate level. For reportedly filtered water samples, in the urban setting, only the type of filter (gravity water filter with ceramic candle versus advance water filters such as the Unilever Pure it, Hindustan Unilever Limited, Mumbai, India) was associated with higher levels of contamination at the bivariate level, whereas in the rural setting, both transferring water to another container and microbial quality of the source water were associated with higher levels of TTC contamination (Supplemental Table 5).

DISCUSSION

These two case studies provide an insight into the manner in which HWT is practiced among households that are

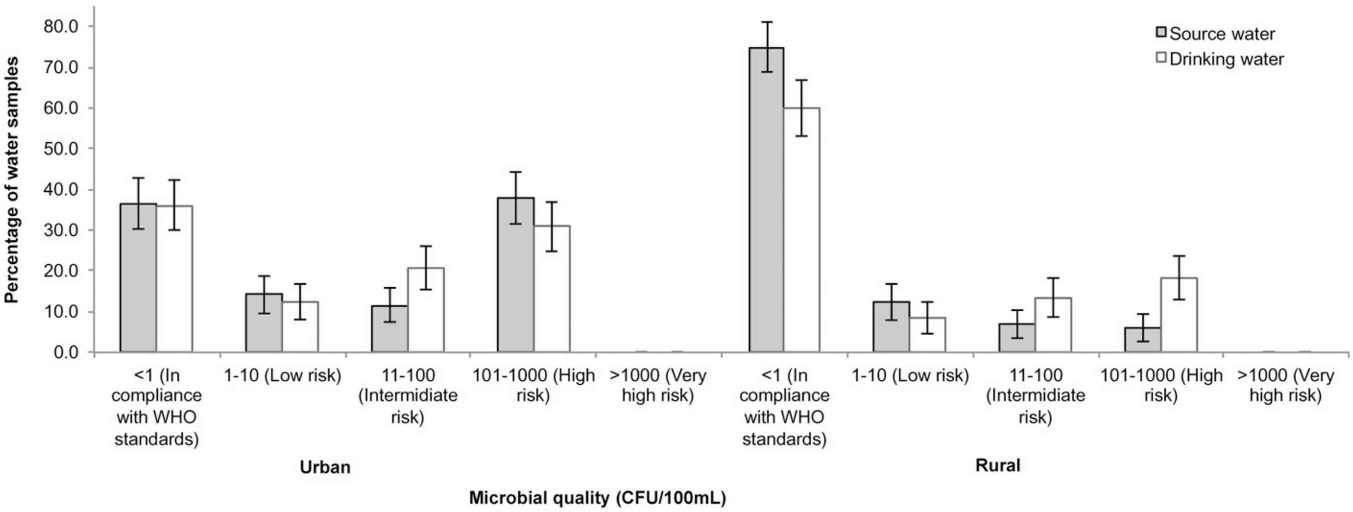

FIGURE 2. Microbial quality (thermotolerant coliform colony-forming units/100 mL) in source and drinking water samples of households reporting to use adequate methods of household water treatment (HWT) at baseline (U: N = 219, R: N = 203).

identified as HWT users according to current, official monitoring mechanisms in an Indian setting. In this setting, as opposed to the case studies in Peru, and particularly in Zambia, reporting of HWT was consistent during the duration of follow-up in both urban and rural contexts. All households in the urban setting and 93.3% of those in the rural setting reported HWT at both questioning events. Furthermore, of those that reported to filter their water at baseline, 80.5% and 93.8% or urban and rural households had a filtering device in use at home. Furthermore, 98.8% of urban households and a slightly lower percentage in rural households (74.7%) reported to have treated water at all three sampling events. Additionally, based on self-report, supplementation of treated water with untreated water did not appear to be a common practice in this setting; however, as in the other two case studies conducted in Zambia and Peru, supplementation appeared to be more common in rural (21.9%) than urban (4.1%) settings. Unfortunately, verification of nonsupplementation using objective indicators during the home observations was extremely challenging. Unlike the case studies in Peru and Zambia, there was not much evidence for reporting bias of other potentially useful indicator of HWT, such as supplementation and frequency of HWT use. However, of the few discrepancies observed, most occurred in the rural context, as was the case in the Peruvian and Zambian studies. Of interest too, is the fact that, as opposed to the other replicate studies, the consistency of the reported method of HWT during follow-up was relatively low in this setting. This could have implications for global estimates of different HWT methods used.

Despite the consistent reporting of HWT during the duration of this study, the microbial quality of drinking water of those households identified at baseline as users of adequate methods of HWT was suboptimal. Drinking water of urban households reporting the use of adequate HWT methods was of no better quality than source water, whereas rural households were consuming water of significantly worse microbial quality than their source water. While at individual rounds of data collection higher percentages of water samples were free of TTC, only 13.7% of urban and 25.8% of rural households identified as users of adequate methods of HWT had water free of TTC at all three sampling events. Similar results were observed in the replicates studies of Zambia and Peru.[24,25] These findings suggest that a one-point assessment of HWT use based on self-report is a poor predictor of drinking water quality in the home. Furthermore, these results suggest that a cross-sectional microbial assessment of drinking water quality, as opposed to a longitudinal assessment, might overestimate the microbial quality of drinking water in the home.

In this setting, reported filtration at baseline seems to be a better predictor of microbial water quality than boiling; however, while households that reported filtration (or were able to show a filter upon request) had water significantly of better quality than their source water, only a fraction of households (U: 24.4%, R: 50.0%) had water free of contamination throughout the study.

Likewise, a substantial proportion of samples that were claimed to be treated at the time of collection, as opposed to reported treatment status at baseline, were contaminated with TTC. Again, filtration appeared to be more effective than boiling.

When we examined the determinants of microbial quality of water samples reportedly treated with adequate methods, the reported method of treatment, the quality of the source water, and in the rural setting, the reported time since treatment, were significantly associated with contamination of drinking water. This would be suggestive of ineffective treatment and posttreatment recontamination or possibly, misreporting of the actual HWT status of some of the drinking water.[31,32] When the determinants of microbial quality were assessed separately for reportedly filtered and boiled samples a similar picture emerged. Certain HWT-specific variables such as the type of water filter used, transferring water from the filter to another container, or temperature of the boiled water were associated with fecal contamination. This puts into question the potential of HWT, as actually practiced by vulnerable populations, to improve water quality and prevent waterborne diseases. The suboptimal performance of boiling in LMICs has been extensively described in the literature.[20,32–36] In this setting, other water handling variables, such as type of container or method of serving the drinking water were not significantly associated with microbial quality. This could partly be due to a lack of power to detect such differences, as this study was not powered for such calculations, or to a true lack of association. While some studies have identified these as important determinants of microbial quality of drinking water,[37] other studies have not detected such an association.[38,39]

These findings raise important questions about the value of the current monitoring mechanisms to assess HWT practices for public health and policy purposes. While in this setting, both urban and rural households appear to practice HWT in a consistent manner and reflect their self-reported status after implementation of the JMP core questions on HWT use, the lack of microbial effectiveness of HWT in households identified as users of adequate HWT according to current monitoring methodology, raises important questions about the value of these core questions as proxy indicators of drinking water quality at the home.

The addition of further questions such as the verification of HWT products in the household, the frequency of HWT usage, as has been done in a small number of DHS surveys,[40,41] and the supplementation of treated with untreated water when in the home, to the nationally representative surveys, could improve the quality of the use of HWT estimates as a proxy for water quality in the home. However, as shown in the other replicate studies conducted in Peru and Zambia, some of these additional questions can be subject to courtesy of other reporting bias. Additionally, there is often strong opposition to the inclusion of additional questions and specially, observations, to these already lengthy surveys. Nevertheless, the WHO has developed a toolkit for the monitoring and evaluation of HWT and safe storage programs that aims to provide standard indicators of HWT that assess, in a more objective manner, the correct and consistent use of the practice.[42]

Other strategies, including the actual monitoring of water quality at the household-level would be favored. In fact, monitoring of fecal contamination is considered by the JMP to be one of the next steps in improving global monitoring of access to safe drinking water.[43–45] Additionally, water quality testing of safely managed water sources is to be an integral part of the Sustainable Development Goals targets on drinking water, sanitation, and hygiene.[46] However, issues with high temporal variability of microbial quality in drinking water, including seasonal trends, as well as the limitations in representativeness of one-point assessments as opposed to longitudinal assessments, will need to be taken into account if these monitoring strategies are to provide accurate and representative data.[47]

The addition of water quality monitoring at the household level in nationally representative surveys, at least is a representative subsample of households, in combination with these additional questions on HWT use would allow for the exploration of a set of key questions or observational indicators on HWT use, such as the ones suggested above, that could act as reliable predictors of drinking water quality at the household level. This would allow for a much more cost-effective and logistically feasible strategy than water quality monitoring.

Of interest too, is the fact that in this setting, rural households had both drinking and source water of higher microbial quality than their urban counterpart, despite the fact that sanitation was suboptimal. This is at odds with the literature, which indicates a higher risk of contamination in both source and stored water samples in rural areas compared with urban areas.[48,49] In this setting, most urban households relied on private or public piped connections, which are associated with higher levels of microbial quality.[50] Furthermore, during the execution of the study, we were made aware that the piped network of both private and public connections had recently been upgraded, which might explain the high microbial quality observed in this setting.

There are a number of limitations to this study. The two study sites were not randomly selected and so are not representative of India as a whole or other countries. Furthermore, the study was conducted over a short period of time, which coincided with the monsoon season; the study is thus not representative of HWT practices during other seasons. Additionally, we cannot exclude the potential for reactivity due to the repeated visits and spot-checks.[51,52] With respect to the home observations, the limited number of hours of observations and the reliance on male staff limit the validity and representativeness of these data. A further limitation of this study was the fact that water samples were collected from the storage container as opposed to the drinking cup. Several studies have shown drinking water to be significantly more contaminated when collected from drinking cups as opposed to storage containers,[31,35] and thus our study may overestimate the microbial quality of drinking water in homes of practitioners of HWT. Additionally, we did not have sufficient power to undertake a rigorous analysis of determinants of microbial quality of drinking water, specifically for reportedly filtered or boiled water samples. Also, the water quality of the source water in the rural setting was of relative high standards; this might have limited our ability to detect improvements in water quality associated with HWT use. Due to time restrictions and the desire to not elicit reactivity of participants, sampling of water sources was not conducted prior to the start of the study to assess levels of contamination. Finally, the major limitation of this study is the overreliance on self-reported data to assess consistent HWT use, which is a reflection of the lack of robust indicators of HWT use, especially for boiling.

CONCLUSIONS

- Reporting of HWT and availability of treated water (based on self-report) among households identified as users of adequate HWT according to current monitoring standards was consistent in the urban setting and slightly less so in the rural setting. Nevertheless, half of households reported a different HWT method in at least one of the three sampling events.
- Supplementation of treated water with untreated water (based on self-report) was uncommon in both settings, but particularly in the urban setting, suggesting high levels of consistent HWT use.
- Households reporting filtration at baseline were more likely to have water of better quality than their source water than households reporting boiling.

- Only 13.7% of urban and 25.8% of rural households identified as users of adequate HWT had water free of TTC at all three water sampling points. This lack of effectiveness of HWT practices raises important questions not only about the value of the JMP data for public health and policy purposes, but also about the potential contributions that HWT can make in LMICs to control waterborne diseases.
- As these findings are in agreement with other case studies from LMICs, it seems fitting to reconsider how HWT should be promoted, implemented, and monitored to ensure its microbial effectiveness in day-to-day conditions, critical to achieving the full health impact of this intervention.

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