Safety of packaged water distribution limited by household recontamination in rural Cambodia

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ABSTRACT

Packaged water treatment schemes represent a growing model for providing safer water in low-income settings, yet post-distribution recontamination of treated water may limit this approach. This study evaluates drinking water quality and household water handling practices in a floating village in Tonlé Sap Lake, Cambodia, through a pilot cross-sectional study of 108 households, approximately half of which used packaged water as the main household drinking water source. We hypothesized that households purchasing drinking water from local packaged water treatment plants would have microbiologically improved drinking water at the point of consumption. We found no meaningful difference in microbiological drinking water quality between households using packaged, treated water and those collecting water from other sources, including untreated surface water, however. Households' water storage and handling practices and home hygiene may have contributed to recontamination of drinking water. Further measures to protect water quality at the point-of-use may be required even if water is treated and packaged in narrow-mouthed containers.

Key words | kiosks, packaged water, water quality, water storage

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INTRODUCTION

Diarrhoeal diseases cause an estimated 10% of child deaths worldwide (Liu *et al*. 2012). Gastrointestinal illnesses disproportionately affect children and other vulnerable groups who may be at greater risk of severe outcomes due to dehydration and other effects of persistent diarrhoea. This preventable burden of disease is partly attributable to poor access to safe drinking water. Unfortunately, the development and maintenance of infrastructure for piped, adequately and consistently treated water remains an elusive goal in many settings. In Cambodia, a majority of people live in rural areas and the under five mortality rate is among the highest in Asia (Varis 2008). Waterborne and water-related diseases are widespread owing to lack of access to sanitation and limited access to safe piped or other improved sources of water, especially in rural areas. In 2010, only 20% of rural households had access to improved sanitation and 42% lacked access to an improved water source, with only 5% of rural households having a household water connection to a piped supply (UNICEF & WHO 2012). Infrastructure access is poor but quickly expanding.

The expansion of packaged drinking water – treated water in sealed containers – has largely been limited to high-income markets. An emerging focus of this delivery model is lower-income settings, with local entrepreneurs selling high-quality water in containers to people willing to pay full price (Vijaya Lakshmi *et al*. 2011; Sima *et al*. 2012). Distribution points are often referred to as 'kiosks'. Although the business case for developing packaged water micro-enterprises is compelling, little is known about the relative safety of the drinking water as delivered to households or its potential for becoming recontaminated in storage. High levels of drinking water contamination can occur within the household owing to improper storage and poor hygiene practices, which can significantly impact microbiological water quality (Wright *et al*. 2004). Stored water contamination can pose significant risks (Jagals *et al*. 2013).

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We examined drinking water quality and water handling practices among households using packaged water as a primary drinking water source compared with those using other sources of water. The study was conducted in a commune in the south of the Tonlé Sap basin, where greater than 90% of households are floating. The commune houses three independent, donor-initiated, private packaged water treatment plants that distribute treated water in sealed containers. These plants treat water through sedimentation, anthracite filtration, microfiltration and UV disinfection, with prices from 500 riel (US$.25) per 20 L container in 2010. The stated goal of these schemes is to deliver safe drinking water through profitable enterprises run entirely by commune members. The aim of this study was to assess the household-level drinking water quality improvements afforded by supplying treated, packaged drinking water in this context.

MATERIALS AND METHODS

Study setting

The basin of Tonlé Sap Lake houses almost one-third of the Cambodian population (Heinonen 2006), with many living directly on the water in houseboats. Adequate human excreta disposal is uncommon in floating communities; makeshift latrines in this area consist of an open hole on wooden planks in which the excreta passes directly into the lake, which is the source of drinking water.

We collected drinking water samples and survey data from 108 randomly selected households. Respondents were given a sterilized sample bottle and asked to take a sample in the same manner they would use to prepare a glass of drinking water, from the drinking water in use by the household at the time of the visit. The interviewer observed and recorded the method in which the respondent poured the water and details of the drinking water storage container. Upon collection, sampling bottles were sealed and kept on ice until they were tested in the field laboratory within 4 hours from the point of sampling. Testing for the faecal indicator thermotolerant coliforms (TTC) in 100 mL samples was carried out by the Oxfam-Delagua water testing kit (2005c). The field-deployable field kit enabled the processing of samples by membrane filtration followed by incubation (16–18 hours) at $44.5 \pm 0.5\,^{\circ}C$ on broth lauryl sulphate media. After incubation, colony-forming units (cfus) were enumerated and recorded as TTC/100 mL. When the total number of TTC on the membrane was too numerous to count (TNTC), the sample was assigned a count of 300 TTC/100 mL (or more, depending on dilution) for purposes of statistical analysis. Domestic water use and handling practices associated with faecal contamination of drinking water were identified via logistic regression and reporting odds ratios (OR) with 95% confidence intervals.

RESULTS

One hundred and eight households provided drinking water samples for this study, representing drinking water for 585 individuals. Households had an average of 5.4 members. Selected household characteristics are presented in Table 1.

Water use and handling

Sixty-two households reported drinking primarily packaged water, while 46 used other sources. Rainwater collection hardware was observed in 32% of households, although this was not a primary water source for any households during the time of the study, in the dry season. Of those buying packaged water, 60% have the water delivered to their homes by boat for a small additional fee.

Many of the households in the commune practised post-collection water treatment. Approximately 89% of households who used packaged water reported treating by boiling (48 households) or filtering using a mineral pot filter (7 households) before consuming. Forty-two per cent of all households reported boiling lake water for drinking. Approximately 32% of households reported using alum to treat lake water. Of the various methods used to treat water on the household level, only boiling had a negative association with presence of TTC ($OR = 0.19$, 95% CI: 0.06, 0.54), across all samples.

Of the households visited, 97% had covered water storage containers at the time of interview, with all households using packaged water using a narrow-mouthed

Table 1 | Selected characteristics of households ($n = 108$) and individuals ($n = 585$) selected for interview

		Reported primary household drinking water source at the time of interview		
	Total	**Packaged drinking water**[a]	**Other drinking water**	***P*-value**
Number (%) of households	108	62 (57%)	46 (43%)	0.50
Mean number of people per household	5.4	5.4	5.6	0.59
Socioeconomic status				
○ Low	38 (35%)	17 (27%)	21 (46%)	0.05[b]
○ Middle	46 (43%)	28 (45%)	18 (39%)	0.54
○ High	24 (22%)	17 (27%)	7 (15%)	0.13
Household has soap on hand	107 (99%)	62 (100%)	45 (98%)	0.25
Self-reported hand-washing				
○ After defecation	94 (87%)	55 (89%)	39 (85%)	0.55
○ Before eating or preparing food	86 (80%)	52 (84%)	34 (74%)	0.21
○ After cleaning a baby's bottom	53 (98%)	33 (97%)	20 (100%)	0.44
Observed latrine in household	89 (82%)	53 (86%)	36 (78%)	0.33
Water storage containers covered	105 (97%)	60 (97%)	45 (98%)	0.99
Mean total drinking water storage capacity (litres)	85	109	55	0.04[b]
Geometric mean thermotolerant coliforms (TTC) per 100 mL	110 (95% CI: 77, 140)	74 (95% CI: 45, 120)	130 (95% CI: 84, 190)	0.35

[a]Primary source of drinking water according to respondent.
[b]Significant at $\alpha = 0.05$ level, Mann–Whitney U test.

storage container. Seventy-two per cent of households using packaged water used a 20 L container sold (and washed between refills) by the packaged water distributor, with 28% of households using a narrow-mouthed 30 L container that is common in the community, without between-fill cleaning by the distributor. Households reporting packaged water as a primary drinking water source used a range of water handling and storage methods, including probable (but unconfirmed) mixing of sources and supplementation of packaged water with other water sources.

Water quality

Baseline measurements of packaged water at the point of treatment as controls were measured on average every 2 days and consistently remained at <1 TTC/100 mL (below lower detection limit), while untreated lake water, tested twice weekly during the 4 week study, was found to contain ≥3,000 TTC/100 mL at each sampling point (exceeding upper detection limit).

Contaminated drinking water was highly prevalent, with 75% of households found to have drinking water containing >1 TTC/100 mL. Samples from households drinking packaged water had a geometric mean of 74 TTC/100 mL (95% CI: 45, 120), while households using other, non-packaged sources of water contained a geometric mean of 130 TTC/100 mL (95% CI: 84, 190). There did not appear to be a significant difference between contaminated water in packaged or non-packaged water sources ($P = 0.35$).

DISCUSSION

Most household drinking water samples tested in this study were positive for the faecal indicator TTC, regardless of the source, treatment or storage conditions. Water produced by packaged water treatment plants showed high levels of contamination (geometric mean of 74 TTC/100 mL) after household-level storage and handling, although it was of consistently high quality when tested directly from the treatment plant (<1 TTC/100 mL). Safe water is therefore subject to recontamination, apparently even after delivering the water in narrow-mouthed containers. The odds of observing ≥1TTC/100 mL were not different between households consuming packaged water and those using other sources (OR = 1.35, 95% CI: 0.56, 3.2).

Household water treatment and storage

Household water treatment was common in the study area, with 83% of households reporting treating drinking water at home by adding alum, boiling or using filters, even among those who use primarily packaged water. Almost one-third of households interviewed use alum to treat water, which may be a cost-effective way of achieving clearer, better tasting, and possibly safer drinking water (Clasen *et al.* 2007). In this study, of the 13 water samples tested in which alum had been added as the only form of treatment, results varied from <1 to 11,900 TTC/100 mL, with a mean of 1,214 TTC/100 mL.

Boiling water, regardless of the original source, was negatively associated with TTC levels (OR = 0.19, 95% CI: 0.06, 0.54). Boiled water may be at risk of household-level recontamination if not stored properly, and may be practised inconsistently in Cambodia (Brown & Sobsey 2012). In this study, boiled water samples varied in safety, ranging from <1 to 600 TTC/100 mL with a mean of 87 TTC/100 mL.

Household drinking water in the study setting is primarily stored in large plastic tubs with removable lids. Households commonly used plastic dippers or cups to collect water, drink directly out of the dipper or cup, and then place back into the drinking water, which can potentially lead to contamination due to hands repeatedly coming into contact with the water (Levy *et al.* 2008). Although packaged water is delivered in narrow-mouthed containers, households often re-stored, mixed or treated water at the household level, and some households chose to use their own household containers for storage of drinking water.

Local treatment plants have made an effort to provide packaged water in a way that will prevent household contamination by offering the option to purchase the water in sealed containers with taps. This prevents contamination by allowing individuals to access the water without using hands or dippers. The extra cost of the sealed containers may reduce uptake; we found only 19% of all containers were of the improved type. Other households supplied their own narrow-mouthed containers, or appeared to re-use containers between opportunities for refilling them. User water management behaviours were complex and may have contributed to TTC counts in drinking water.

This study had a number of known limitations. First, as a cross-sectional study, our findings capture a 'snapshot' only and cannot examine seasonal trends. The study was carried out during 4 weeks in July, beginning in the dry season and ending as the rainy season was starting. Many of those interviewed stated that lake water was safer to drink in the rainy season because it did not look as dirty. It is likely that microbiological quality of water and household water management will vary greatly throughout the year, with increased use of rainwater in the rainy season. Second, apart from directly observable variables or objective water quality measures, data were collected from respondents in an interview setting. Response bias was a possibility. Third, the small sample size provides only limited statistical power to compare water quality data between sources.

CONCLUSIONS

Results from this study suggest that packaged drinking water in this context did not result in safer drinking water at the point of consumption, as indicated by TTC counts. Contamination of drinking water appears to be occurring in the household, regardless of the original source, and despite narrow-mouthed packaging of treated water. We do not suggest that there are no benefits of these packaged drinking water schemes – they may produce water that is chemically or microbiologically safer than lake water by other measures – but the threat of recontamination cannot be ignored, and user behaviours may limit the effectiveness of these schemes as delivery models for safe drinking water.

There appear to be high levels of household drinking water contamination in the study setting, regardless of source water safety, which is consistent with previous research on household contamination (Wright *et al.* 2004). This underscores the importance of disease transmission occurring in the domestic domain (Cairncross *et al.* 1996).

While many households spend a sizeable percentage of their income on packaged water to avoid drinking contaminated water, there are many routes in which the water may become contaminated once the treated water has been purchased and before consumption (Wright *et al*. 2004; Levy *et al*. 2008). The safety of packaged water distribution schemes should be assessed in further studies of water quality and associated health outcomes. Programmes that aim to deliver safe water must account for post-treatment recontamination, which is a function of household water use behaviours and domestic hygiene.

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