

Drinking water quality for peri-urban residents in Phnom Penh, Cambodia

K. Thomas, E. McBean and H. M. Murphy

ABSTRACT

Piped distribution systems are limited to major urban centres in Cambodia, leaving the residents of peri-urban communities to rely on a variety of surface, rain and groundwater sources for their drinking water supplies. This paper examines microbial water quality results from two of Phnom Penh's peri-urban communities, and describes relationships between water source and treatment type, study site and storage vessel, relative to water quality guidelines. Treating water by boiling was a common practice, although the majority of residents indicated using boiling times far greater than required, which may impact adoption rates. A statistical difference is described between boiled water by source type, with boiled shallow well water having elevated *E. coli* levels. The only household drinking water type that met WHO guidelines most of the time was boiled rain or tank (vendor) water (56%); boiled rain or tank (vendor) water stored in a kettle, bucket/cooler or bucket with spigot met guideline values 69, 43 and 60% of the time, respectively. The highest quality water is from boiled rain or tank (vendor) water taken directly from a kettle. The findings described provide some insight on how to prioritize water options for various uses.

Key words | Cambodia, drinking water, microbial, peri-urban, Phnom Penh, water quality

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INTRODUCTION

An estimated 13% of urban and 42% of rural Cambodians lack access to an improved drinking water source (WHO/UNICEF 2012). Piped water distribution systems are largely limited to major urban centres, with 63% of residents having piped water on premises compared to 5% for rural populations (WHO/UNICEF 2012); the remainder of the population must rely on a variety of other water sources. Each of the water sources available to residents of peri-urban areas have limitations: surface water and shallow groundwater sources often have high microbial contamination; rainwater is good quality but limited in availability; and elevated arsenic and iron levels, parameters of health and aesthetic concerns, respectively, have been identified in the groundwater of various regions in Cambodia (Polya *et al.* 2005; Feldman *et al.* 2007).

Since different water sources and treatment alternatives have implications on the risks of diarrhoeal disease for peri-urban residents, this paper examines the circumstances confronting the peri-urban residents of Phnom Penh (referred to

as the 'City'), Cambodia, through a case study approach and provides some measured evidence as to the practices and challenges in these communities.

BACKGROUND

Drinking water resources and diarrhoeal diseases

While the majority of inhabitants in the developed world access drinking water through household piped connections, in many developing countries it is not unusual to find that a variety of drinking water sources, of varying desirability and availability, are used within a single community. WHO/UNICEF (2012) categorizes drinking water sources as being 'improved' (e.g., piped water into a dwelling, borehole, protected dug well and rainwater collection) or 'unimproved' (e.g., unprotected well, vendor-provided water, such as from

a tanker truck, or bottled water). Without direct access to water in the home, water must be collected elsewhere and then transported to, and stored in, the home prior to use. Water stored in the home has been demonstrated to be generally more contaminated than the source water (Clasen & Bastable 2003; Jagals *et al.* 2003; Wright *et al.* 2004; Oswald *et al.* 2007).

Faecal-oral waterborne disease transmission may result in a wide range of human illnesses, with severity levels ranging from mild gastroenteritis and diarrhoea to more severe forms of diarrhoea and other possibly fatal diseases. Diarrhoeal disease is highly endemic in communities that lack improved water supplies. Although drinking water is only one of several possible pathways for most waterborne pathogens, interventions to improve water quality are generally effective in reducing diarrhoeal disease rates (Clasen *et al.* 2007). Microbial contamination of drinking water in communities lacking improved water supplies is likely to contribute significantly to the burden of diarrhoeal disease.

Cambodian drinking water supplies

Piped distribution systems are largely limited to the central core of Cambodia's major cities. Outside these areas, different combinations of surface, ground and rainwater are used. Surface water is collected directly from water bodies, groundwater is collected using shallow wells or tube wells/boreholes, rainwater is captured using rainwater harvesting systems and water is also purchased from vendors. The use of different water sources varies by season.

Historically, a common approach taken by non-governmental organizations (NGOs) to supply improved drinking water supplies to communities lacking piped distribution systems was to provide shallow or tube wells. However, this strategy has proven problematic given the presence of arsenic and iron in the groundwater supplies of certain regions. Arsenic has been identified in groundwater in various parts of Cambodia, with a grouping of highly hazardous concentrations immediately south and south west of Phnom Penh (Polya *et al.* 2005). Iron is the most common dissolved mineral of aesthetic concern in Cambodian groundwater, with levels far exceeding the aesthetic limit being widely detected (Feldman *et al.* 2007).

Approximately 1.5% of the Cambodian citizens use household level BioSand or ceramic water filtration or

chemical treatment, and many more treat some or all drinking water through boiling, coagulants or traditional cloth filters (Brown *et al.* 2007). Two common household water treatment (HWT) options in Cambodia are ceramic water purifiers (CWP) and Korean water filters (KF).

Since 1993, Cambodia's Phnom Penh Water Supply Authority (PPWSA) has undergone dramatic improvements in its piped water supply system. The PPWSA now reports 100% coverage of central Phnom Penh (Chan 2009). Ongoing expansion to the surrounding districts is planned and urban poor communities have been given 'high priority' (Chan 2009). City-supplied water is around one-quarter of the cost of water supplied by private vendors; however, the connection fee is often cost-prohibitive for the urban poor (McIntosh 2003). The PPWSA is making efforts to expand services to the urban poor through the policy 'Clean Water for the Poor', which provides discounts, subsidies and instalment payment plans on the cost of the connection fee (PPWSA 2012).

Peri-urban communities of Phnom Penh

Private ownership of land in Cambodia was abolished during Khmer Rouge rule between 1975 and 1979, and Phnom Penh's population was forcibly displaced to rural areas (Durand-Lasserve 2007). Following the fall of the Khmer Rouge regime in 1979, the City repopulated. Centrally located buildings were taken over, and settlements began to develop on vacant lands. These improvised communities are now considered illegal (UN-HABITAT 2003). With ongoing economic development of the City, land occupied by squatters has become increasingly desirable, resulting in forced evictions (Durand-Lasserve 2007) and the development of peri-urban settlements scattered on the outskirts of Phnom Penh. In peri-urban areas, water and sanitation needs are met through a wide range of small-scale, informal means.

METHODS

Study communities

Two communities were selected as study sites: Christ Family Development Community Veal Sbov (VS) and New Village, Prey Sala (PS). Both communities had been recently

resettled from central Phnom Penh locations, and experienced a significant decline in drinking water quality and access as a result of their relocation.

VS is located approximately 10 km east of Phnom Penh. The community is very low income. At the time of this study, 409 people in 83 households officially resided in VS. PS is located 12 km west of Phnom Penh. No list of community members was available. PS is more established than VS, and residents have larger homes and more amenities. In both communities, the increased distance to central Phnom Penh since their forced resettlement from the central city to the peri-urban areas resulted in a greater burden on households, due to increased commuting time and transportation costs.

The water sources available in VS and PS are summarized in Table 1.

All households available during the first site visit to each community were approached and asked to participate in the

study; informed consent was obtained from those interested in participating. The study included 46 households; 20 from VS and 26 from PS. Not all households were available on a weekly basis, and two dropped out prior to the end of the study.

The average numbers of household members were 5.6 and 5.8, in VS and PS, respectively. The majority of households (68% in VS and 76% in PS) were home to children under the age of 5. Based on self-reported monthly household income and observed wealth indicators, the residents of PS were typically wealthier than those of VS.

Data collection

The study consisted of 11 weeks of sampling conducted over 12 weeks; one site was visited in each of the first two weeks

Table 1 | Summary of drinking water resources available in Veal Svov and Prey Sala

Type	WHO classification	Veal Svov details	Prey Sala details
Rainwater	Improved	Primary water source used in the rainy season Typically collected in plastic buckets	Primary water source during the rainy season Typically collected in large rainwater harvesting jars
Unprotected shallow wells	Unimproved	Three uncovered, cement-walled and one uncovered, hand-dug, unlined, shallow well Buckets used to withdraw water Commonly used Elevated arsenic contamination levels	One communal, uncovered, concrete-lined shallow well and some private wells Buckets used to withdraw water Used by only one study household
Tube well	Improved	N/A	Two tube wells of unknown depth. Significant aesthetic issues due to elevated iron levels, but no significant health risks identified
Tanker truck (tank) (vendor) water	Unimproved	N/A	A water vendor uses a tanker truck to deliver water to the community Delivery may take place to individual households or to a privately owned water tank from which water is resold The source of this water is unknown. Some households indicated that the source was treated City water, while others expressed concern that it was from a surface water source
Surface water	Unimproved	Site of garbage and waste disposal Not commonly used for drinking water due to perception of water quality	N/A
Bottled water	Unimproved ^a	201 bottles of treated water sold in the community Origin of water unknown	N/A

^aBottled water is considered 'improved' only when the household uses a different improved source for cooking and personal hygiene (WHO 2011).

of sampling and both sites were then visited each week for the remaining 10 weeks to collect water samples from households. Laboratory analyses were conducted at the Resource Development International Cambodia (RDIC) Water Quality Laboratory.

A comprehensive survey on household details, water sources, water quality perception, source water desirability, diarrhoeal disease prevalence, water treatment and storage, and hygiene and sanitation coverage was conducted at each household during the first week of sampling and is described in Thomas (2010). In all following weeks, a brief survey was given at the time of water sampling on water type, treatment and storage of household water samples. Observational data on the condition of the storage container and other relevant details were also gathered at each visit.

The water samples represented the drinking water available in the household at the time of sampling: study participants provided samples by treating the sample bottle as a household drinking cup.

Laboratory methods

All water samples were analysed for pH and turbidity, and the microbial parameters of *E. coli* and total coliforms (TCs). Samples were kept in an ice-filled cooler until being returned to the laboratory, where they were refrigerated prior to analysis, which occurred within 24 hours.

E. coli was selected as the indicator bacteria for use in this study, as per the recommendations of the WHO (2011). *E. coli* and TC were enumerated using the membrane filtration method (Standard Method-9222B). Differential Coliform Agar with chromogenic agent BCIG (OXOID Culture Media) was used. To ensure quality assurance, at least two dilutions were plated in duplicate for each sample. Samples were incubated for between 22 and 24 hours at 37 °C before enumeration.

RESULTS AND DISCUSSION

The drinking water options available in these communities were examined, to characterize the water quality of sources

available in Phnom Penh's peri-urban areas. A log transformation was used to produce normally distributed microbial data sets on which other statistical analyses could be performed. Statistical analyses were performed using Microsoft Excel 2007.

Household drinking water quality

Data aggregation by source and treatment type

Where defensible on the basis of statistical tests of water quality, data aggregation using *T*-test and ANOVA analyses were used to combine some water source types to decrease the number of categories; for example:

- Boiled rain and boiled tank (vendor) water had the same water quality ($p = 0.336$) and were aggregated, but boiled shallow well water must be considered separately ($p = 0.00103$)
- The two types of water filters (CWF and KF) produced the same quality of water ($p = 0.971$).

A summary of the *E. coli* data for household water is presented in Figure 1.

Several findings are evident from the results:

- *The variations within individual household drinking water types are substantial.* Generally, five orders of magnitude were evident in *E. coli* concentration, with the exception of shallow well water, which had consistently high levels of contamination
- *Water treated by filtration or boiled rain/tank water is not different in water quality ($p = 0.47$) and hence treatment type selection should be based upon other factors such as cost and ease of use*
- *Untreated rainwater, tank and bottled water produced similar water quality ($p = 0.98$)*
- *Boiled shallow well water had the highest *E. coli* concentration of boiled water samples:* A statistically significant difference in *E. coli* levels was found between boiled rain/tank and shallow well water ($p = 0.0026$).

Rainwater is a commonly used rainy season water source, while bottled and tank water are typically used as supplemental rainy season water sources and are often primary dry season water sources; therefore, households

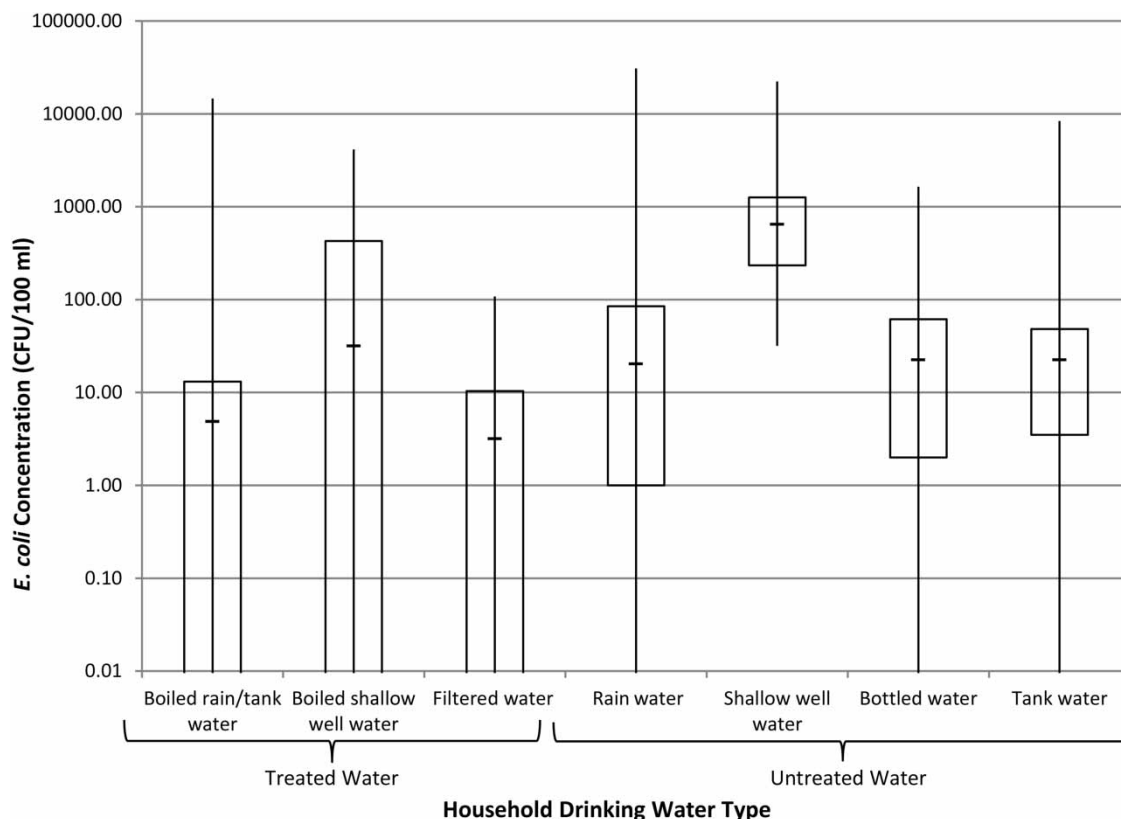


Figure 1 | Box and whisker plot displaying geometric mean, 25th and 75th percentile, maximum and minimum *E. coli* concentration values (CFU/100 ml) for each household water sample category.

using these water types can expect consistent water quality throughout the year. Due to the high costs of bottled and tank (vendor) water, households should use rainwater for as long as possible, and invest in increased rainwater storage capacity, as feasible.

Although there should be no difference in the *E. coli* levels of different types of properly boiled water, boiled shallow well water had the highest *E. coli* concentrations of boiled water samples. It may be that actual boiling times were inadequate or that boiled shallow well water has a higher recontamination potential. Shallow well water at VS was found to be the most highly contaminated source water type, with an *E. coli* concentration geometric mean of 2,744 CFU/100 ml. No statistically significant difference was found between untreated rain, tank, bottled water and boiled shallow well water ($p = 0.45$), which has implications on how a household might want to prioritize its water options, especially for drinking water purposes.

Implications of storage containers

The type of vessel used to store drinking water may have a significant impact on recontamination potential. Studies have shown that the cause of faecal bacteria found in boiled water is recontamination rather than poor boiling practices (Clasen *et al.* 2008).

Several different types of storage containers were in use in the study communities. ANOVA analyses were performed to determine how vessels should be grouped together for boiled rain, tank and shallow well water, untreated rainwater and untreated shallow well water; the results are summarized as follows:

- No statistically significant differences in microbial water quality were found between bucket and cooler samples of rain/tank water, boiled shallow well water and untreated rainwater: Covered bucket and cooler samples

were aggregated for boiled rain/tank water ($n = 59$ for covered bucket and $n = 7$ for covered cooler; $p = 0.859$), boiled shallow well water ($n = 12$ for covered bucket and $n = 5$ for covered cooler; $p = 0.165$) and untreated rainwater ($n = 55$ for covered bucket and $n = 11$ for covered cooler; $p = 0.79$).

- No statistically significant differences in microbial water quality were found between covered and uncovered buckets and jars for untreated rainwater ($p = 0.88$ for buckets and $p = 0.85$ for jars).
- Storage containers had a significant impact on water quality for boiled rain/tank water and, to a lesser degree, for boiled shallow well water: impact of storage containers on *E. coli* concentrations appears at the 95% level for boiled rain/tank water and the 85% level for boiled shallow well water.
- When water is treated, storage of the water post-treatment plays a significant role in maintaining water quality: Previous studies have shown that decline in water quality from source water to point-of-use is proportionately greater with lower initial concentrations (Wright *et al.* 2004; Oswald *et al.* 2007), but this relationship was not evident here. *E. coli* levels in untreated rainwater are similar to boiled shallow well water, which indicates that the differences arising from storage containers on water quality cannot be explained by differences in initial starting concentration.

The highest quality boiled water samples were boiled rain or tank water taken directly from a kettle or pot (geometric mean of 1.9 CFU/100 ml). This result was expected, given the lower contamination opportunity due to vessel sterilization. However, it is not always practical to store boiled water in kettles due to the low storage volume. It may be wise to prioritize the use of this water for higher risk individuals (e.g., young children). It should be noted, however, that participants noted that young children do not like to drink warm water, and will choose instead to drink cooler, untreated water.

The second highest quality water was boiled rain/tank water from covered buckets with spigots. At the 90% level of significance, a statistically significant difference ($p = 0.010$) in *E. coli* concentrations exists between water stored in covered buckets with (geometric mean of

2.75 CFU/100 ml) and without spigots (geometric mean of 8.92 CFU/100 ml). The use of a spigot reduces potential contamination arising from dipping collection devices into the bucket.

The average *E. coli* concentration for 20 l bottles (geometric mean of 31.8 CFU/100 ml) was three times greater than that of the other storage devices. This result may be due to difficulties cleaning the bottles, given their narrow mouths, and because they require more handling to pour water.

Boiling duration

WHO Guidelines (2011) indicate that boiling water is an effective method to kill disease-causing pathogens. Households stated boiling times from 5 to 30 min, several times longer than recommended by organizations such as the WHO (2011) and USEPA (2012). However, responses may not accurately represent reality, but instead reflect what participants believe is the 'correct' response. The numbers of responses for each range of boiling times were: less than 10 min (10), 10–15 min (104), 15–20 min (22) and 20–30 min (9). The accuracy of reported boiling durations was not confirmed. There was no statistically significant water quality difference for samples of different reported boiling durations ($p = 0.351$). A belief that treating water by boiling requires extended durations (with significant cost and time implications) may limit the widespread adoption of this practice.

Water quality by community

The only water types that could be compared across communities were boiled and untreated rainwater. No statistical difference was found in average *E. coli* concentrations in boiled rainwater samples between communities. However, a higher level of contamination was detected in untreated rainwater samples from PS, possibly due to the larger vessels used. Larger rainwater harvesting devices (jars and tanks), with volumes of 500 l and greater, are typical in PS (average 6.5 per household), compared to the small plastic buckets commonly used in VS (average 2.1 buckets per household; the three that used jars had an average of 1.7). Households using buckets

for rainwater collection typically have storage of up to a few days, while those with multiple jars are able to store water for several weeks, up to the duration of the rainy season (Murphy et al. 2009).

Probability of meeting water quality guidelines

The WHO (2011) Guideline value for verification of microbial water quality is that *E. coli* or thermotolerant coliform bacteria must not be detectable in any 100-ml sample. However, the WHO (2011) recognizes that a high proportion of household and small community drinking-water systems in the developing world fail to meet this requirement. The second edition of the WHO Guidelines (WHO 1997) presents a 'typical' classification system for microbiological water quality data, based on *E. coli* concentration, as follows:

- <1 CFU/100 ml – in conformity with the WHO guidelines;
- 1–10 CFU/100 ml – low level of contamination;
- 11–100 CFU/100 ml – intermediate level of contamination;
- 101–1,000 CFU/100 ml – high level of contamination;
- >1,000 CFU/100 ml – very high level of contamination.

A similar *E. coli* classification system, including all but the >1,000 CFU/100 ml level, is presented in the current WHO Guidelines (2011), as part of an example assessment for priority of remedial action for household drinking water systems.

The probability of household water supplies falling into each of the categories was determined using probability of exceedance analysis. The only water type that met the WHO Guidelines most of the time was boiled rain/tank water, which had no detectable *E. coli* colonies in 56% of samples. When examined by storage type, boiled rain/tank water stored in a kettle had *E. coli* levels that met guideline values 69% of the time, and no sample had high or very high levels. Similarly, boiled rain/tank water stored in a bucket with spigot passed the WHO guidelines 60% of the time, and no samples exceeded very high levels. These results demonstrate the benefits associated with storing water in a kettle or bucket with spigot.

No untreated shallow well water samples had fewer than 10 CFU/100 ml of *E. coli*. The majority of untreated shallow well water samples (84%) had 'high' or 'very high'

levels of contamination. Boiled shallow well water and untreated rainwater had similar results, although untreated rainwater had fewer samples in conformity with WHO guidelines and fewer that fell in the 'high' or 'very high' category.

Source water quality

T-test and ANOVA analyses were used to determine how to categorize and aggregate the source water quality data. The *E. coli* data from the two PS tube wells ($p = 0.750$) and the three concrete-lined and one hand-dug shallow well in VS ($p = 0.223$) were aggregated. A summary of the source water *E. coli* data is presented in Figure 2.

Well and surface water results

No statistically significant differences were found in the microbial results of water samples from the three concrete-lined and one hand-dug shallow wells of VS, which was unexpected given the shallow depth and surface contamination potential of the hand-dug well. However, this result may be due to the fact that only four samples were taken of the hand-dug well, as it was inaccessible due to flooding after the fourth week of sampling. When the VS shallow wells were examined by type, the geometric mean of the *E. coli* data was 2,444.6 CFU/100 ml for the concrete-lined wells and 6,346.1 CFU/100 ml for the hand-dug well.

No significant difference was found between the quality of surface and shallow well water in VS ($p = 0.32$), suggesting that the shallow wells may be hydraulically connected to the highly contaminated surface water source. This hypothesis is supported by the much lower levels of contamination in the similarly constructed and maintained shallow well in PS. In PS, tube wells provided microbiologically safe water, but went unused due to aesthetic problems caused by high iron levels.

The concrete-lined shallow well of PS had lower *E. coli* concentrations compared to the shallow wells of VS ($p = 0.00028$). While the shallow wells in VS were surrounded by homes, the shallow well in PS was located in the private yard of a shop on the outskirts of the community; as a result, the VS wells may have been more exposed to human and animal waste, and accessible to more residents, which may

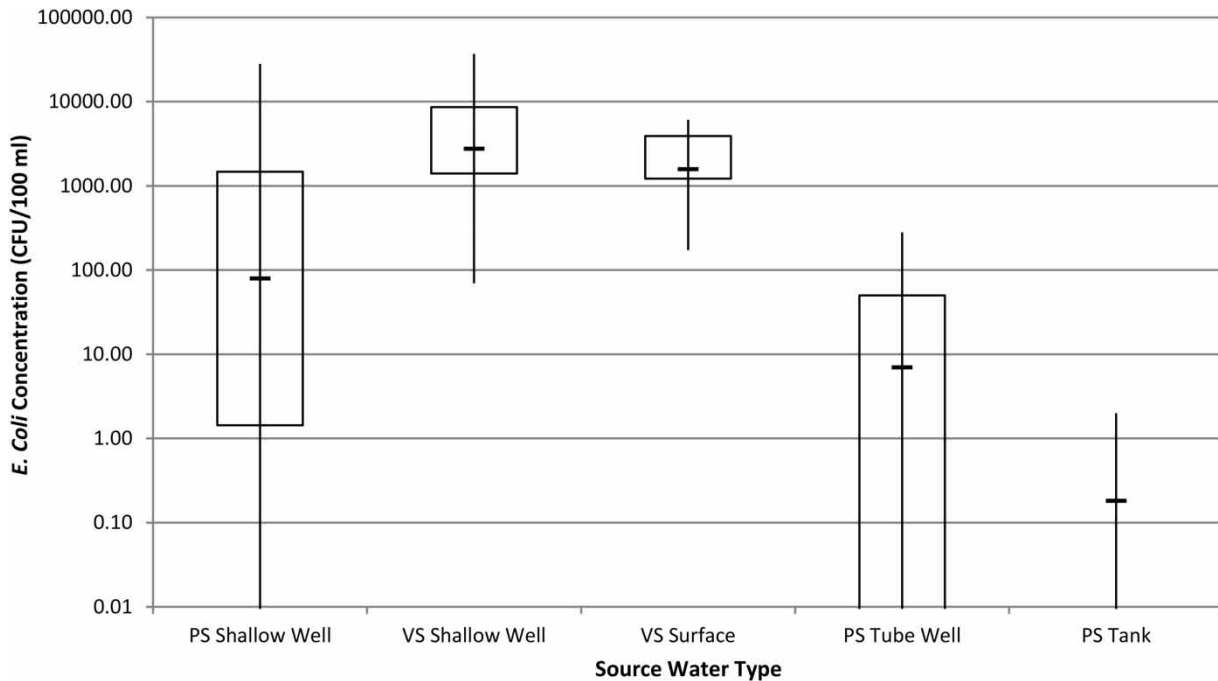


Figure 2 | Box and whisker plot displaying geometric mean, 25th and 75th percentile, maximum and minimum *E. coli* concentration values (CFU/100 ml) for each source water type.

have resulted in more contamination during the drawing of water.

No statistically significant difference was found between the *E. coli* concentrations of the PS shallow well and tube wells ($p = 0.198$). This result was not expected: it was thought that the tube wells (an improved source) would provide higher quality water than the unprotected shallow wells (an unimproved source). While there were no obvious problems with the platform, pump, pump stand or mount, the depths of the tube wells are unknown and they may be under the influence of surface water. These findings suggest that increased emphasis should be placed on constructing protected shallow wells in PS; currently only unprotected shallow wells are available.

Microbial water quality by study site

The primary drinking water option used at both study sites in the rainy season is rainwater. The PS households typically have much greater rainwater storage capacity compared to those of VS, resulting in the switch to dry season water sources occurring later in PS, although the quality of this water may degrade over time. Rainwater is among the

higher quality source waters available in the communities, and all households prioritized it as their preferred rainy season water source.

In the dry season, once rainwater reserves run dry, households must switch to different sources. VS residents use shallow well or surface water, or purchase expensive bottled water – none of these options are considered ‘improved’ by the WHO definition. Arsenic levels in VS shallow wells are elevated, exceeding WHO guidelines (10 µg/l), although they meet less strict Cambodian guidelines (50 µg/l). In PS, residents use the shallow or tube wells at no direct cost, or purchase water from a tanker truck water vendor; in practice, residents tend to use only shallow well or tank (vendor) water (both unimproved sources) rather than the tube wells (an improved source) due to concerns with the aesthetics and taste of the tube well water caused by elevated iron levels. The shallow well at PS appears to provide water of similar microbial quality to the PS tube wells, while the shallow well water available in VS had microbial levels nearly 3,500% higher. The microbial quality of the dry-season water resources available to VS residents are of much lower quality than those available in PS.

CONCLUSIONS

For much of the year, residents of the study communities rely on unimproved water sources to supply their drinking water. While all participants reported using rainwater (an improved water source) as their primary rainy season water source, unimproved water sources tend to be used during the dry season. The wealthier residents of PS typically have high rainwater storage capacity and some residents are able to maintain reserves well into the dry season, minimizing the need to purchase water from a vendor (i.e., bottled or tank water), which provides water of comparable quality at a far greater cost. Shallow wells are available in both communities, but are much more widely used in VS, being the only free option available once rainwater reserves are exhausted. The VS shallow wells have statistically similar contamination levels to the highly polluted surface water (possibly due to a hydraulic connection), and provided unsafe water, often even when boiled. In PS, tube wells provide microbiologically safe water, but are unused due to aesthetic problems caused by high iron levels.

The relationships of water quality with factors such as water and treatment type, study site, storage and vessel included some unexpected findings. A statistical difference was found between boiled rain/tank water and boiled shallow well water, which had elevated *E. coli* levels, perhaps due to higher contamination potential caused by the handling of the highly contaminated source water. No statistically significant difference was found between untreated rain, tank, bottled and boiled shallow well water ($p = 0.45$), which has implications on how to prioritize water options. Households should focus on improving rainwater harvesting capacity and safe water handling/storage (stored in containers with spigots or kettles following boiling); this approach also addresses concerns related to elevated arsenic and iron levels in groundwater. NGOs should consider these findings when providing interventions in these and similar communities.

Other key findings of this study include:

- The impact of storage containers was evident for *E. coli* levels of boiled rain/tank and shallow well water; this relationship was less strong for boiled shallow well water and not apparent for untreated rainwater.

- The highest quality boiled water samples were taken directly from a kettle or pot (1.9 CFU/100 ml); it may be wise to prioritize the use of water stored in kettles for higher risk individuals.
- The vast majority of participants who boiled their water reported boiling times far greater than required. The perception that extended boiling durations are required may limit more widespread adoption of this practice.
- The only household drinking water type that met WHO guidelines most of the time was boiled rain/tank water (56%). Boiled rain/tank water stored in a kettle, bucket/cooler or bucket with spigot met guideline values 69, 43 and 60% of the time, respectively.
- No untreated shallow well water samples had fewer than 10 CFU/100 ml of *E. coli* and the vast majority (84%) had high or very high levels of contamination.

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