

## Access to Safe Drinking Water in Cambodia: Available Sources and Point-of-Use Water Treatment

Marcus F. Aguilar

Faculty Sponsor: Joseph M. Brown, Ph.D.

Department of Civil, Construction, & Environmental Engineering, University of Alabama, Tuscaloosa, AL 35487, USA

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*Water is a resource that Cambodia has in abundance, but health problems persist in rural areas of the country due to unsafe drinking water. The Cambodian government in association with non-governmental organizations (NGO) and the private sector has promoted implementation of methods to filter and/or disinfect water at the point of use, but current programs have encountered obstacles. Engineers Without Borders at the University of Alabama visited the rural areas of Kampong Speu Province and Siem Reap Province, Cambodia to perform an observational study of potential drinking water sources and identify the problems the country faces in treating water for consumption using an in-home ceramic water purifier. Results suggest that typical drinking water sources are unsafe and that household water filtration is a useful but complex intervention strategy for addressing this problem.*

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### Introduction

Cambodia is the poorest country in Southeast Asia and has the least developed infrastructure in the region, due partly to the recent history of genocide and conflict from the 1970s–1990s and the associated loss of investment and human capital [13]. The Khmer Rouge regime massacred from 2–4 million Cambodians, many of which were of the educated class, leaving the country with a lack of doctors, lawyers, engineers, teachers, and other trades that require formal training. Foreign investment and development has slowly returned to Cambodia, but 19% of Cambodians still subsist on less than 1 USD per day [12]. Infrastructure development and access remains low compared with neighboring countries.

Water is abundantly available in Cambodia, with the Mekong, Bassac, and Tonlé Sap Rivers as well as the largest freshwater lake in Southeast Asia in Tonlé Sap Lake, with an average surface area of 8,155 km<sup>2</sup> [2]. Available surface water resources are subject to large yearly fluctuations, as the country experiences the cycle of dry and rainy seasons. Groundwater is also widely available in most areas of the country, and has been accessed through both hand dug wells and the more advanced drilled wells with hand pumps. UNICEF, other donors and aid organizations have rapidly scaled up access to wells in rural areas. Groundwater is increasingly suspect as a source of drinking water in some areas due to arsenic contamination, however [3].

In spite of the high availability of drinking water sources in Cambodia, the lack of infrastructure development means the country faces serious challenges with respect to safe drinking water. An estimated 39% of the rural population of the country uses unimproved drinking water sources [14], and the danger of this is manifested in the Kingdom's high infant mortality rate of 82 per 1000 live births [18]. 56.2% of post-neonatal deaths in Cambodia are attributed (at least partly) to the onset of diarrhea caused by the consumption of unhealthy water [5]. Diarrheal disease is the number one cause of death in children under 5 years of age in Cambodia [9].

Engineers Without Borders at The University of Alabama (EWB-UA) visited Cambodia in May 2009 and completed an initial survey of drinking water in two rural areas. EWB-UA's objectives in these areas were (1) to assess safety of a variety of source waters of different types in rural Cambodia, and (2) to examine the use of one household-scale water treatment device, specifically the ceramic water purifier, now being used throughout Cambodia. To fulfill objective (1), EWB-UA focused on a specific area of Kampong Speu Province, in which to investigate the quality of typical drinking water sources in rural Cambodia. Although this area is relatively close to Phnom Penh, it does not enjoy the benefits of access to modern infrastructure. Cambodians in this province rely on surface water stored in detention ponds or protected or unprotected wells. Typically, individuals collect the

water themselves in buckets or other containers, or have water delivered to them by a tank vehicle. The two main measures the group used to assess the quality of selected water sources were thermotolerant coliform (TTC) bacteria and arsenic. TTC is a bacterial indicator of waterborne fecal contamination. Arsenic is an emerging problem found in groundwater sources in Southeast Asia, particularly in the Mekong delta region, and is naturally occurring [11]. The emergence of arsenic as a health problem in Cambodia has caused consumers to switch from ground water sources that are generally lower in microbial content to surface water sources that do not contain arsenic. However, surface sources are more likely to have high amounts of TTC. As a result, consumers are at a higher risk of diarrheal disease due to the consumption of low quality surface water [3]. The World Health Organization states that TTC should not be detectable in any 100 mL sample of water, and the level of arsenic must be below 10 ppb in order for the sample to be considered safe to drink [17]. Since 49.3% of Cambodia's rural population relies on unprotected ponds, rivers, streams, or wells for drinking water [2], treatment is usually required to make water safe. In rural areas, an emerging strategy for treating drinking water is point-of-use (POU) filtration, such as rapid sand or ceramic water purifiers (CWP) shown in Figure 1, which are household-scale water treatment technologies. Centralized treatment facilities have not been established in rural Cambodia [2].



**Figure 1.** The outside and inside of a ceramic water purifier.

Because large scale public treatment systems may be decades away for much of rural Cambodia, POU treatment options have been widely promoted and are identified as an effective option in both cost and removal capabilities. The CWP is a viable option, as it is produced by NGOs in-country with locally

available clay and milled rice husks [8]. These two components are mixed and pressed into a clay pot, then fired and cured. The process of the firing burns out the rice husks, leaving a porous ceramic structure. Finally, the pot is coated with a solution of silver nitrate, a microbiocidal compound designed to increase the effectiveness of the filter by reducing bacteria and algae on contact. This ceramic pot is placed in a plastic receptacle which allows for safe storage of clean water. Then it is sold to consumers at a cost of around 10 USD [8]. The CWP has been found to consistently reduce *E. coli* and other bacteria in water by up to 99.99999%, with typical reductions of 99% in field use. It has a useful life of around five years, although implementers often suggest replacement after 1-2 years [15]. EWB-UA's objective (2) was fulfilled by investigating the use of the CWP as a POU method in Siem Reap Province.

The bio-sand filter is an intermittently operated slow sand filter that is similar in application to the CWP. The bio-sand filter is capable of 98% removal of TTC [10] and is also capable of removing arsenic at a rate of 87-96% [6]. This added benefit makes it ideal for use in Cambodia, though in the areas EWB-UA visited, the CWP was much more common. This POU method shares many of the same qualities as the CWP, and it is used by over 1.5 million people worldwide [10].

Disinfection through household chlorination is another option for POU treatment, although it is more effective as a secondary treatment following filtration. Chlorine is the most common disinfectant because it is cost effective and practical to apply through tablets or in liquid form. Free chlorine has a microbial baseline reduction of 99.9%, but as turbidity is lessened (through filtration or other methods), it is capable of microbial reduction up to 99.9999% [10].

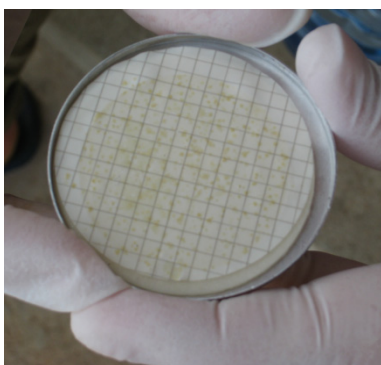
Before filtration or disinfection was available, consumers would boil water prior to drinking to assure its safety, and the majority still does boil some or all of their drinking water [1]. This treatment is only effective if the consumers wait for the water to boil, and then cool before drinking. Boiling water is quantitatively prohibitive in that a family could not possibly boil more water at one time than their largest cooking container. Boiled water often also becomes contaminated during storage [1]. The

method is therefore effective from a purely removal standpoint but is not practical for the long-term.

### Methods

EWB-UA tested water sources from lakes, wells, and rivers to assess drinking-water quality. Representative sources were identified by our partner NGO, Lien Aid, which has an active water development program across rural Cambodia. Water quality metrics were set by the group before surveying to evaluate the merits of each source.

These metrics provided a basic algorithm intended to identify water sources for present consumption and future development by Lien Aid, who is planning to build water treatment plants in the area. The team recorded a wealth of information for each site, including location (as indicated by GPS), road access, seasonality, access to the public, and any other notable information. These variables were measured by careful observation of each site and its surroundings by the team and by interviews with Cambodians who were familiar with the area. Three samples were taken from each source in order to measure TTC, arsenic, fluoride (sent away for analysis), and free and total chlorine for sources such as wells that may have been treated. The team measured TTC using a DelAgua test kit (DelAgua, Robens Centre, UK). This test consisted of a membrane filtration method. Once the samples were filtered, they were incubated at  $44.5^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$  on selective growth media. After approximately 18 hours, the TTC colonies can be visualized on the filtered graph paper (Figure 2).



**Figure 2.** TTC count on filtered graph paper. TTC colonies represented by yellow blotches.

The test kit provided everything necessary for the process, with the added benefit of an internal battery that could sustain the incubation process even in areas of intermittent or non-existent power supply. The team used the arsenic Econo-Quick test kit to determine arsenic levels in source bodies. This simple colorimetric test required the mixture of the sample water with three reagents to form arsine gas, which was then detected and quantified by a strip of reactant paper. The results of these tests and the observational information are tabulated in Table 1.

EWB-UA then moved to the province of Siem Reap to perform a non-random survey and observational study of filter use by the residents of villages around the city. The purpose of this was to:

1. Assess the value of the ceramic water purifier to users.
2. Test the functionality of the filters in terms of actual removal and practical use.
3. Observe the practices of the subjects pertaining to the collection, filtration, and consumption of water for all uses.

The completion of these three objectives provides an understanding of the relationship that the rural Cambodian has with his or her CWP, and offers a glimpse of the wider issues related to the use of household water treatment in Cambodia. The survey consisted of an interview with the user and a collection of water samples at the input and output of each CWP. This allowed EWB-UA to connect each subject's behaviors pertaining to the filter with quantitative filter performance results. It also created an association between the necessity of filtration as revealed by the statistics from Kampong Speu, and the actual practice of filtration as observed in Siem Reap.

### Results and Discussion

Each site had different qualities but, in general, the conclusion drawn from the survey is that rural Cambodians do not have access to clean drinking water, unless they venture to filter it themselves. Of the 22 drinking water sources (Table 1), only two of the sites met the WHO standard for safe drinking

water of 0 TTC colony forming units (cfu)/100 mL, and one sample was within the threshold of moderate risk (11-100 cfu/100 mL). All other samples (19 of 22) were classified as high risk sources (>100 cfu/100 mL) should they be consumed untreated. Since there are no large-scale drinking water treatment facilities in the province, it is left up to the consumers to practice POU water treatment (e.g., filtration or disinfection) to ensure that the water they drink will not make them sick.

The tested wells did not have results that were noticeably more favorable than any surface water source. Only one of the five wells with available TTC data met WHO standards, and one of the wells far exceeded the safe threshold for arsenic. Arsenic testing showed that low levels of this compound are present in the region, in the range of 0-25 ppb, but a low level indicator test is required to determine if these sites would actually meet the worldwide standard of 10 ppb. In general, all tested sites met the Cambodian national standard of 50 ppb, which is a performance-based standard [3].

Chanthual Lake and Krang Ambel Pond are potentially the best sources in Kampong Speu Province for the placement of a Lien Aid water treatment facility, based on year-round availability of water at those sites and good resident perception of the water quality. However, at present their TTC count is too high for consumption. EWB-UA sampled the water that a vendor was collecting at the Banteay Kmae pond, in which results indicated that it contained enough TTC to categorize it as a moderate-risk source. Vended water in the area is not subjected to regulation and is generally delivered untreated. Since consumers have no way of checking whether the water is safe to drink, this causes a potentially harmful situation. Centralized piped water that is treated to international standards would be a vast improvement over current conditions. Until that service is provided, residents of Kampong Speu Province and other rural areas will need to treat drinking water themselves using POU water treatment methods.

EWB-UA's work in Siem Reap (Supplementary Tables S1 – S3) identified existing problems with POU filtration of source waters. First, it was clear through the interview process that the subjects would be hesitant to reveal the full truth about their filter use.

**Table 1.** Results of site assessment in Kampong Speu Province, Cambodia.

| Location                        | Water Source              | Arsenic (ppb) | Thermotolerant Coliform Count (colonies/per 100 mL) |
|---------------------------------|---------------------------|---------------|---|
| Psar Wat Ong                    | River                     | 10            | TNTC  |
| Rolaing Sen Health Center       | Well                      | 25            | 391   |
| Wat Ong Mi Trey                 | Spring fed                | 10            | TNTC  |
| Chanthual Lake                  | Lake, Fed by River        | 5             | 1767  |
| Krang Ambel Village pond        | Krang Ambel Channel       | 10            | TNTC  |
| Banteay Kmae                    | Rain Fed Pond             | 5             | 100   |
| Krang Ambel Marsh               | Rain Fed Pond             | 10            | TNTC  |
| Banteay Kmae Jr. High School    | Tube Well                 | 5             | 0   |
| Phnom Pagoda Pond 1             | Pond, Possibly Spring-Fed | 10            | TNTC  |
| Okoki Village channel           | Mountain Stream Fed       | 0             | 467   |
| Phnom Pagoda Pond 2             | Pond                      | 10            | 4400  |
| Kantuot Primary School Well     | Tube Well                 | 10            | -   |
| Wat Phnom Primary School Well 1 | Tube Well                 | 10            | 1000  |
| Krang Mkak Village Well         | Tube Well                 | 5             | -   |
| Wat Phnom Primary School Well 2 | Tube Well                 | 10            | 300   |
| Krang Mkak Village Pond         | Pond                      | 10            | 0   |
| Prey Kvaov Village Well         | Tube Well                 | 10            | TNTC  |
| Prey Tnot River                 | River                     | 10            | 833   |
| Pray Kvaov Village Stream       | Stream                    | 0             | 3500  |
| Thboung Ang Village Pond        | Pond                      | 10            | 7600  |

\* TNTC – Too Numerous to Count

Instruction on the use, maintenance, and importance of the CWP was provided upon purchase of the filter,

and many of the subjects claimed to be following these guidelines closely. In several instances, however, EWB-UA found it highly unlikely that the subjects were truthful about the amount they used the filter. Interview number 1 (Supplementary Table S1), for example, started with the subject explaining that she used the filter daily and cleaned it regularly. After inspection of the filter and more thorough questioning, the subject admitted that the filter had not been used since the family left for the rice fields weeks earlier, and it had not been cleaned in at least one month. Furthermore, this subject did not believe that the well water was the cause of her diarrhea, stating that good taste was indicative of cleanliness. The subjects appeared to believe that it was better to imitate competence with the filter than provide actual information, a nuance that the interviewers realized almost immediately. This apparent disconnect between the subject's perception of the purpose of the interview, and the interviewer's desire for truthful answers, causes a problem that tends toward bias in surveys. When asked if the subjects were happy with the filter, all answered in the affirmative. However, when asked what they would make different about the filter, it was clear that they were not entirely satisfied with the performance of their CWP. Several explanations for these observations are possible. It is possible that the subjects expected further questioning if they did not answer in an appeasing manner, and they would have preferred to answer as few questions as possible. It is also possible that they associated the EWB-UA interview team with the NGO that taught them how to use the filters, in which they wanted to prove that they were responsible enough to merit their ownership of the filter. The subjects' hesitance to be forthcoming with the interviewers suggests that they have been taught how to use the filters without the benefit of knowing the importance of water sanitation. Strange explanations for how the filters function, as shown in interviews 11 and 13 (Supplementary Table S2), support this notion. The Khmer have survived for generations without water treatment. Providing them a filter and claiming that it will make them healthier is simply not enough to convince them of the importance of the CWP. User-focused, ongoing, participatory health and water education programs may help reinforce proper use of the filters.

Relevant to the consistency in which the subjects used their filters, EWB-UA discovered that for several months of the year, the Khmer do not use their filters simply because they are not at home. POU filtration works on the assumption that the user spends much of his/her time around the unit. Since Khmer families (or at least the men of working age) move to the rice fields, where they spend weeks on location raising a crop, the filter will most likely go unused by the absent parties in this time period. This fact is detrimental to the usefulness of the filter. Only one of the subjects that mentioned this problem suggested that it would be possible to take the filters to the fields, and it was evident that much disuse was due to this cause. An ephemeral solution to this problem would be to incorporate portability in the design of the CWP, possibly by adding handles and making it less susceptible to breakage. The answer to the cause of the problem, in reality, is that the subjects need to be more informed on the importance of the filters to their health. Local people must understand that drinking untreated water could cause sickness or death.

A complaint that occurred in 15 of the 37 interviews was that the CWP was too small, or the flow rate was too slow to maintain sufficient clean water for a family. The average number of children per family in Cambodia is 4.2, significantly higher than the world average of 2.6 [7]. A reasonable consumption estimate is 19.8 liters per day with 4.2 children, 2 parents, and an average consumption rate of 3.2 liters/person/day [4]. The optimal flow rate of the CWP is 1.8–2.5 liters/hour [8], so a family would have to run their filter anywhere from 7.9–11 hours each day, assuming it runs constantly, to provide sufficient drinking water for their family. This is not a realistic proposition for Cambodian families. The resolution of this problem ought to be investigated further by CWP suppliers.

Results from water sampling suggested the following points to our team. First, water quality testing can be challenging in technologically less developed countries without proper equipment. The team also noted that water testing methods that provide instant results would revolutionize water testing in such situations, providing consumers with information on water safety and the efficacy of treatment. Also, the CWPs are not always as effective

*in situ* as they are in a laboratory environment (lab studies have shown that CWP's are capable of 99.99999% reduction of coliform bacteria, see Introduction). Only three of the twenty samples that had valid results at the filter spigot met the WHO standard of 0 TTC colonies per 100 mL of water. Seven of the twenty samples had more colonies than could accurately be counted (upper detection limit of 300), and the remaining filters registered varying amounts of colonies. No correlation between consumer attitude and filter output results were apparent. However, the results collected suggest that actual filter performance in the home of the end-user was lower than expected. The total sample size of EWB-UA's survey was too small to make generalizations about overall CWP performance in Cambodia. However, it is sufficient to say that poor drinking water quality can persist even though a filter is used. Ultimately, our study was limited by a low sample size and interpretation problems for both the water quality data and the observational and interview data collected in households of users. We can conclude, however, that available sources of drinking water are unsafe and the use of a household filter may not be an effective intervention. Health and hygiene education and support to users will help in making this a more effective strategy for improving drinking water at the point of use.

### Conclusion

The complexities of the issues that surround clean drinking water in Cambodia are related to environmental, social, and economic factors. The ceramic water purifier is one promising option for treating drinking water to potable standards, when properly used. Piped drinking water may be decades away in rural Cambodia. However, since Cambodia has sufficient water resources, the potential for water treatment is great. Although the CWP is capable of a high degree of microbiological performance, the results from EWB-UA's survey showed that ownership of a filter does not imply proper use or any use at all. The survey showed that lack of knowledge and apathy toward the filter marginalized its benefits. Communities would benefit from health and hygiene education in support of filter implementation projects.

### Acknowledgements

The EWB-UA team would like to thank our hosts in Siem Reap who welcomed us into their homes and provided us the information to make this possible. We would also like to thank Ben Davis at ADRA Cambodia and his associates that translated and facilitated our work around Siem Reap. Also, the group sends thanks to the members of Lien Aid that worked with us in Kampong Speu. The members of EWB-UA that were part of the team in Cambodia were: Will Black, Billy Clark, Sonja Gregorowicz, Rebecca Midkiff, Andrew Magee, Ynhi Thai, Lissa Petry, Rob Quinney, Dr. Phillip Johnson, Dr. Joe Brown, and myself, Marcus Aguilar.

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*Marcus Aguilar is a December 2009 graduate of the University of Alabama from Houston, Texas. He graduated Magna Cum Laude with a Bachelor of Science in Civil Engineering, and he conducted his research for this paper during his undergraduate career. He was also a Presidential Scholar and a National Hispanic Merit Scholar.*