Field Report: Multi-Pathway Exposure Assessment of Fecal Contamination in Formal Neighborhoods and Informal Settlements in Siem Reap, Cambodia

October, 2017

J. Green[1], S. Raj[1], Y. Wang[1], A. Mahtani[1], D. Duong[2], M. Yakushima[3], S. Chhun[3], H. Yakubu[1], J. Michiel[1], J. Wicken[2], CL. Moe[1]

[1]Emory University; [2]WaterAid Cambodia; [3]Water for Cambodia

Informal settlement in Siem Reap

Executive Summary

The population of Siem Reap city, a popular tourist destination in Cambodia, has an annual growth rate of 5.2%. The city includes both formal neighborhoods with secure land tenure and informal settlements. Health disparities exist where those in the lowest wealth quintile have less access to improved sanitation facilities compared to those in the highest wealth quintile, and therefore carry a greater disease burden from poor sanitation (Figure 1). To better prioritize sanitation investments and guide intervention strategies to reduce the risk of enteric disease, it is important to assess the contribution that various environmental pathways have on exposure to fecal matter.

To quantitatively evaluate fecal contamination exposure pathways in five high-density, low-income neighborhoods in Siem Reap, the SaniPath Exposure Assessment Tool was deployed from September to November 2016. The pathways of exposure to fecal contamination presented in this report include: drinking water (bottled, well, and piped municipal), floodwater, raw produce, and ice.

The results from this study show that both adults and children are exposed to fecal contamination through multiple pathways. The dominant exposure pathways were determined by comparing the percent exposed and magnitude of exposure for both adults and children in the study neighborhoods. Dominant pathways for most neighborhoods included raw produce. Recommendations to reduce exposure to fecal contamination among those living in Siem Reap include: 1) practicing hygienic produce production and handling, 2) promoting municipal water access and use, 3) increasing and maintaining street drainage for flood water, 4) improving the quality of bottled water, and 5) regulating and monitoring commercial ice production.

Introduction

Most of the urban low-income populations in Cambodia live in informal settlements that are characterized by small, high-occupancy homes in rented properties without a formal lease agreement with the landlord.[1] Unlike expansive connected slums in other parts of the world, informal settlements in Cambodia are scattered throughout the city on unpaved low-lying public land near wide roads, abandoned lots, railway tracks, and riverbanks. Homes erected in these areas are usually not raised on columns and therefore suffer significant flooding damage during the annual monsoon. [2]

The sanitation conditions of those in the lowest wealth quintile and living in informal settlements are typically inferior to those in the highest wealth quintiles. Although 88% of all urban households in Cambodia reported access to improved sanitation facilities, there are differences in usage between wealth quintiles.[3] In Phnom Penh and other urban areas, only 58% of those in the lowest wealth quintile reported using an improved sanitation source, compared to 97% in the highest quintile.[4]

Low coverage and use of sanitation facilities leads to contamination of food, water, and surfaces, resulting in greater exposure to fecal pathogens. Unfortunately, this exposure can lead to health conditions such as diarrhea, helminth infections, gut dysfunction, impaired cognitive development, malnutrition, and stunting.[5]

Nationally, children of families in the lowest wealth quintile in Cambodia have a higher prevalence of diarrhea (16.1% vs. 11.3%) and malnutrition (stunting : 41.9% vs. 18.5%; underweight: 7.1% vs. 1.7%) compared to those in higher income communities.[6] (Figure 1)

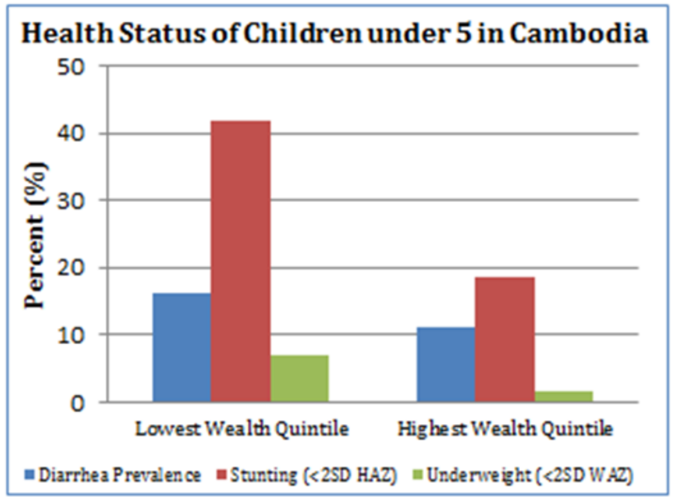


Figure 1: Diarrheal and malnutrition prevalence of children under 5 in Cambodia [6]

Siem Reap (Figure 2) is one of Cambodia's few urban areas and attracts over 2 million people per year to the historic Angkor Wat temples.[6] With rising employment opportunities due to the increase in tourism, the population of urban Siem Reap grew to over 170,000 people in 2008 with an annual rate of population growth of 5.2%.[8] The Demographic Health Surveys (DHS) divides populations into five wealth brackets. Among the population living in Siem Reap province, 30.9% fall into the lowest wealth quintile bracket where living conditions are of inferior quality.[6]

Considering high rates of diarrhea and malnutrition among the reported residents in urban low-income areas, it is important to study whether informal settlements have higher exposure to fecal contamination compared to formal neighborhoods, identify dominant exposure pathways, assess variation in exposure among informal settlements and formal neighborhoods, and identify trends across all neighborhood types. To address this, several research questions were developed:

Research Questions

1. What are the most important pathways of fecal exposure in the five selected neighborhoods in Siem Reap?
2. What are the differences in exposure to fecal contamination between an informal settlement and a surrounding formal neighborhood?
3. Does proximity to an informal settlement affect risk of exposure to fecal contamination in a formal area?
4. What is the comparison of exposure to fecal contamination between formal neighborhoods that do not lie near an informal settlement?
5. What are the differences in exposure to fecal contamination between informal settlements?

Methods

To answer these research questions, the SaniPath Exposure Assessment Tool, developed by the Center for Global Safe Water, Sanitation, and Hygiene at Emory University, was used to quantitatively evaluate the pathways of exposure to fecal contamination in urban environments.

The SaniPath Tool provides information on the frequency of behavior associated with exposure to various environmental pathways and the concentration of fecal contamination in each environmental pathway.

Environmental samples were collected from public areas and household behavioral surveys were administered by a local research team in target neighborhoods.

The environmental samples were analyzed for *E. coli* as an indicator of fecal contamination. This data was combined with frequency data from behavioral surveys and analyzed using the Bayesian Method. A Monte Carlo simulation was then used to generate risk profiles of exposure to fecal contamination.

SaniPath

Why: Assess exposure to fecal contamination

How:

- Environmental samples are analyzed for microbial indicators of fecal contamination
- Behavioral surveys collect information about frequency of exposure to pathways

Where: Municipal water, bottled water, well water, raw produce, floodwater, and ice

Result: Risk profiles show which pathways contribute the greatest risks of exposure to fecal contamination and where to target interventions to reduce exposure

Five neighborhoods within Siem Reap (Figure 3) were assessed using the SaniPath Tool. Three neighborhoods were formal tenured areas and two neighborhoods were considered informal settlements.

Formal Neighborhoods:

Steung Thumey is in the city center and contains both residential properties and businesses. Characteristics that are unique to Steung Thumey include a drainage network for managing flooding, access to piped municipal water, and paved roads, which were not present in the other study sites.

Veal/Trapangses, located in the northwest region of Siem Reap, included two neighborhoods combined and was not near any informal settlements.

Kumruthemey, Formal is a formal tenured region of Siem Reap and surrounds the informal Kumruthemey settlement.

Informal Settlements:

Kumruthemey, Informal is an informal settlement along a single road and is surrounded by the formal neighborhood of Kumruthemey.

Chong Kaosou is a densely-populated informal settlement area surrounded by a formal neighborhood.

Figure 2: Map of Southeast Asia highlighting the city of Siem Reap

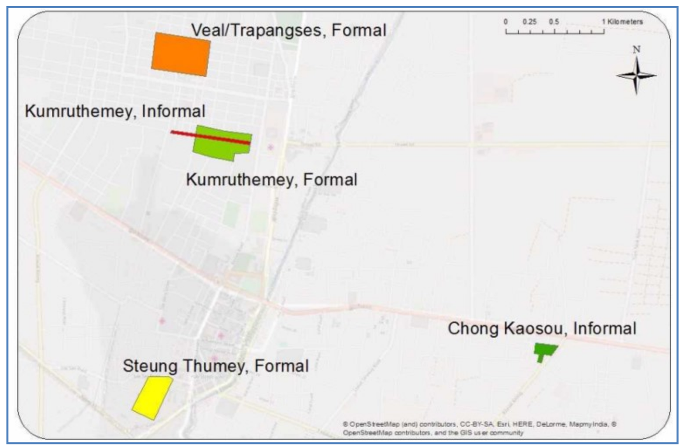


Figure 3: Map of study site neighborhoods in Siem Reap

Table 1: Land tenure status of neighborhoods in Siem Reap included in SaniPath assessment

Neighborhood Name	Land Tenure
Steung Thumey	Formal
Veal/Trapangses	Formal
Kumruthemey	Formal
Kumruthemey	Informal
Chong Kaosou	Informal

From September to November 2016, samples of raw produce from local markets, floodwater, ice from local shops, bottled water from local shops, municipal tap water, and drinking water from borewells were collected from each neighborhood unless a pathway was not present in a given neighborhood . All samples were collected from public areas and not within households. Environmental samples were tested in the laboratory at Water for Cambodia in Siem Reap within 7 hours of collection. All samples were analyzed for *E. coli* using membrane filtration with m-ColiBlue24 Broth. Two to three serial dilutions were used for each sample type and were optimized to capture *E. coli* within the countable range (0-200 Colony Forming Units (CFUs)). A negative control was processed every day.

To assess the frequency with which adults and children interact with the different pathways, the SaniPath enumeration team conducted behavioral surveys in households in the local language, *Khmer*. All households in the neighborhoods were eligible to participate in the voluntary survey. The study team surveyed the household member who managed the water supply in the home, which was usually an adult female. Participants were asked about their frequency of contact with floodwater, and ingestion of raw produce, drinking water from wells, bottled water, and municipal water. They were then asked to estimate the frequency with which their children, ages 10-12, came into contact with those pathways. Behavioral data on ice consumption was not collected.

SaniPath enumerator collecting floodwater samples

Table 2: Number of households surveyed and environmental samples collected in five neighborhoods in Siem Reap

	Behavioral Surveys	Number of Environmental Samples Analyzed					
	Number of Households Surveyed	Raw Produce	Flood Water	Ice†	Drinking Water		
Neighborhood Name					Bottled Water	Well Water	Municipal Water
Chong Kaosou	45	10	10	10	10	10	0
Kumruthemey, Informal	66	13*	10	10	10	10	0
Kumruthemey, Formal	114		10	10	10	10	0
Veal/Trapangses	99		10	10	10	10	0
Steung Thumey	86	10	10	10	10	10	10‡
Total	**410**	**33**	**50**	**50**	**50**	**50**	**10**

* The same 13 produce samples were used for Kumruthemey informal and formal areas and Veal/Trapangses, as all three neighborhoods shared the same produce markets

† Behavioral data was not collected on adult and child exposure to ice

‡ Of the five study neighborhoods, only residents in Steung Thumey had access to municipal water

Results

The results of the SaniPath assessment are displayed as risk profiles, or "people plots", which are shown in the figures on the following pages. The number of red people in the people plots visually represents the proportion of people who are exposed to the specific pathway. The magnitude of exposure to fecal contamination, or "dose" of ingested *E. coli*, is indicated by the shade of red, where darker red refers to greater dose of *E. coli*. The dose is calculated by incorporating data from the analyses of the environmental samples, behavioral surveys, and assumptions based on the scientific literature and previous studies, and quantifies the amount of *E. coli* ingested per month by an average adult or child. In the following pages, the dose is reported using scientific notation in order to more simply express very large numbers. The dose is considered to be different if there is a greater than tenfold difference between two neighborhoods or pathways . The results are displayed in people plots for adults (Figures 4-8) and in tables for children (Tables 3-6).

Research Question 1:

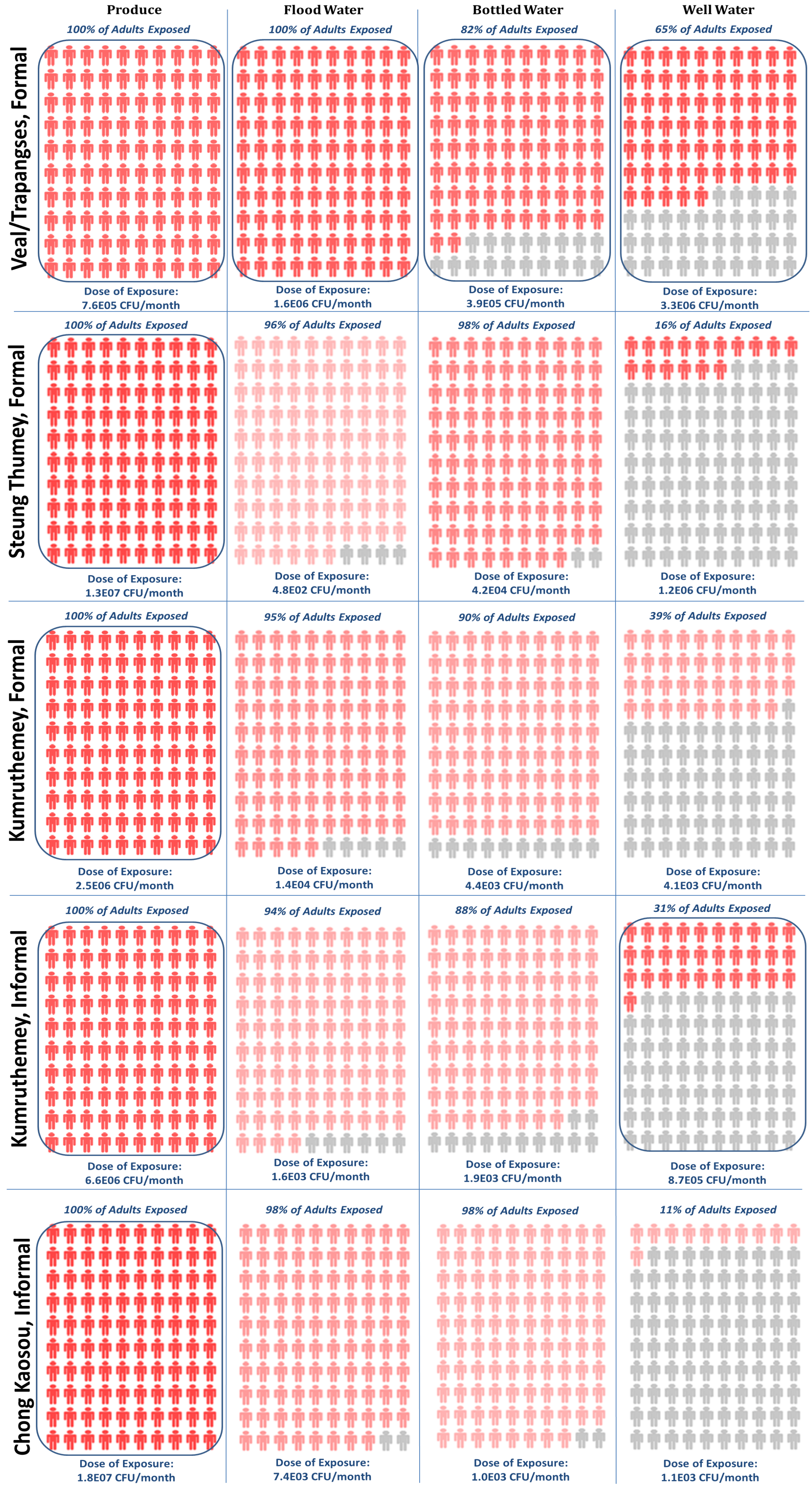
What are the most important pathways of fecal exposure in the five selected neighborhoods in Siem Reap?

Raw Produce: Raw produce was a dominant pathway across all five study neighborhoods for adults. All residents surveyed were exposed to high levels of fecal contamination (>10^4 CFU of *E. coli* per month) from consuming produce. Both adults and children in Chong Kaosou and Steung Thumey were exposed to levels >10^7 CFU of *E. coli* per month from produce.

Drinking Water & Ice: Adults in these neighborhoods were exposed to fecal contamination (>10^3 CFU/month) in bottled water with the exposure dose in Veal/Trapangses exceeding 10^5 CFU/month. Fewer children consumed bottled water than adults. Less than 65% of adults and children in all neighborhoods drank well water. Less than 25% of residents surveyed living in Steung Thumey and Chong Kaosou reported drinking well water. High levels of *E. coli* were found in drinking water from bore wells in the Kumruthemey informal settlement and formal Steung Thumey and Veal/ Trapangses neighborhoods. Fecal contamination in ice samples was highest in the informal settlement of Kumruthemey and lowest in Steung Thumey [Mean (SD): 445.4 CFU/100mL (225.3) vs. 23.2 CFU/100mL (16.3)].

Floodwater: Most adults and children (>80%) in all neighborhoods reported contact with floodwater. Adults were exposed to a relative low dose of *E. coli* (<10^4 CFU/month), except for those residing in Veal/Trapangses (>10^6 CFU/month). Children, however, were exposed to higher concentrations of fecal contamination from floodwater (>10^3 CFU/ month).

Figure 4: Risk profiles for adults for each pathway in every study neighborhood; circled risk profiles indicate dominant pathways



Research Question 2:

What are the differences in exposure to fecal contamination between an informal settlement and a surrounding formal neighborhood?

To address this research question, exposure results from adults and children in the two Kumruthemey neighborhoods (formal and informal) were compared (Figure 5, Table 3). The informal settlement is surrounded by a larger formal neighborhood. These two neighborhoods are in the same geographic location but have different fecal contamination risk profiles.

Raw produce was the dominant pathway in both the informal and formal settlements. Because the produce samples for the informal and formal neighborhoods were from the same marketplace, and the reported raw produce consumption was similar for all adults, the exposure was similar for adults in the informal settlement and in the formal settlement .

When comparing the exposure to *E. coli* from drinking well water, the adults in the informal settlement consumed 200 times more CFU/month of *E. coli* than adults in the formal neighborhood.

However, when analyzing the exposure to adults from consuming bottled water and accidentally ingesting floodwater, those living in the Kumruthemey informal and formal neighborhoods were exposed to similar amounts of fecal contamination.

Adults in both the informal and formal areas of Kumruthemey reported similar frequency of consumption of raw produce, bottled water consumption, and contact with floodwater. The percentage of adults who reported drinking well water in the formal neighborhood was slightly greater than those in the informal settlement (39% vs. 31%). (Appendix A)

Residents of Chong Koasou informal settlement wading through floodwater.
Photo credit: WaterAid Cambodia

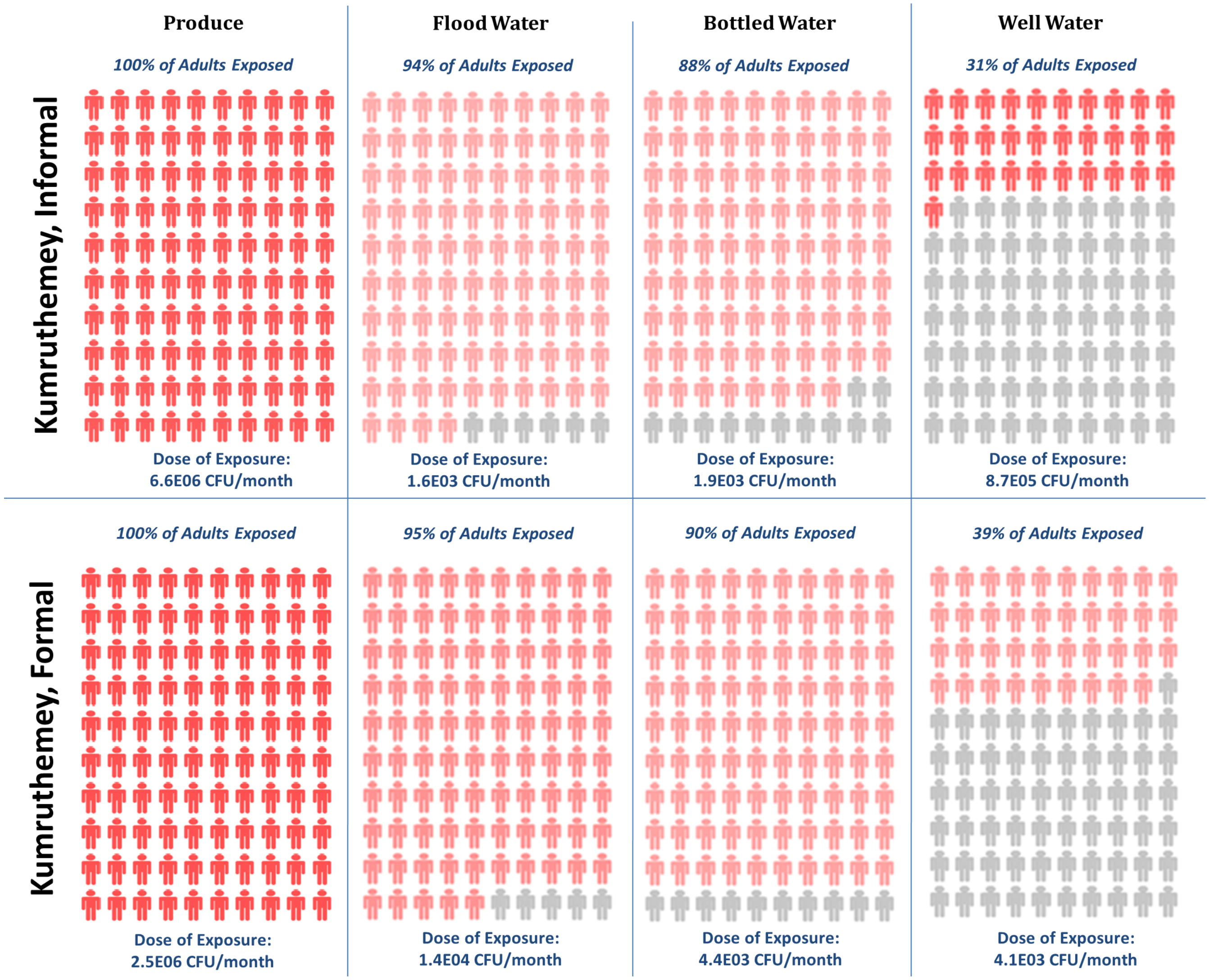


Figure 5: Fecal contamination risk profiles for adults in the informal and formal neighborhoods of Kumruthemey

Fecal contamination of ice samples from the informal settlement of Kumruthemey was approximately ten times higher than that in the formal neighborhood [Mean (SD): 445.4 CFU/100mL (784.2) vs. 48.2 CFU/100mL (50.6)]. (Appendix B)

More children in the informal settlement of Kumruthemey consumed raw produce and came into contact with floodwater than in the formal neighborhood. (Table 3) However, children in the formal neighborhood were exposed to slightly greater levels of fecal contamination when consuming bottled water or having contact floodwater.

Table 3: Percent exposed and monthly dose of *E. coli* estimated for children in the Kumruthemey neighborhoods

	Kumruthemey (informal)		Kumruthemey (formal)	
Pathway	**Dose (*E. coli* CFU/month)***	**Percent Exposed**	**Dose (*E. coli* CFU/month)***	**Percent Exposed**
Produce	8.1E05	100	4.1E05	94
Floodwater	2.5E04	96	5.7E05	80
Bottled Water	1.2E03	62	2.8E03	70
Well Water	4.6E04	22	1.8E03	32

* Dose of exposure quantifies the amount of *E. coli* ingested per month by a child who is exposed to a given pathway, expressed using scientific notation.

Research Question 3:

Does proximity to an informal settlement affect risk of exposure to fecal contamination in a formal area?

To address this question, the SaniPath results from adults and children in the formal Kumruthemey and Veal/Trapangses neighborhoods were compared (Figure 6 and Table 4). Although the formal Kumruthemey and Veal/Trapangses neighborhoods have similar land ownership status and are in the same area of the city, Kumruthemey borders an informal settlement whereas Veal/Trapangses does not.

The dominant pathway for adults in Veal/Trapangses were produce, floodwater, well water, and bottled water, while the dominant pathway for the formal Kumruthemey neighborhood was produce. (Figure 6)

For all pathways analyzed, residents in Veal/Trapangses were exposed to a higher dose of *E. coli* than those in Kumruthemey, except for produce, which was similar for these two neighborhoods. (Figure 6)

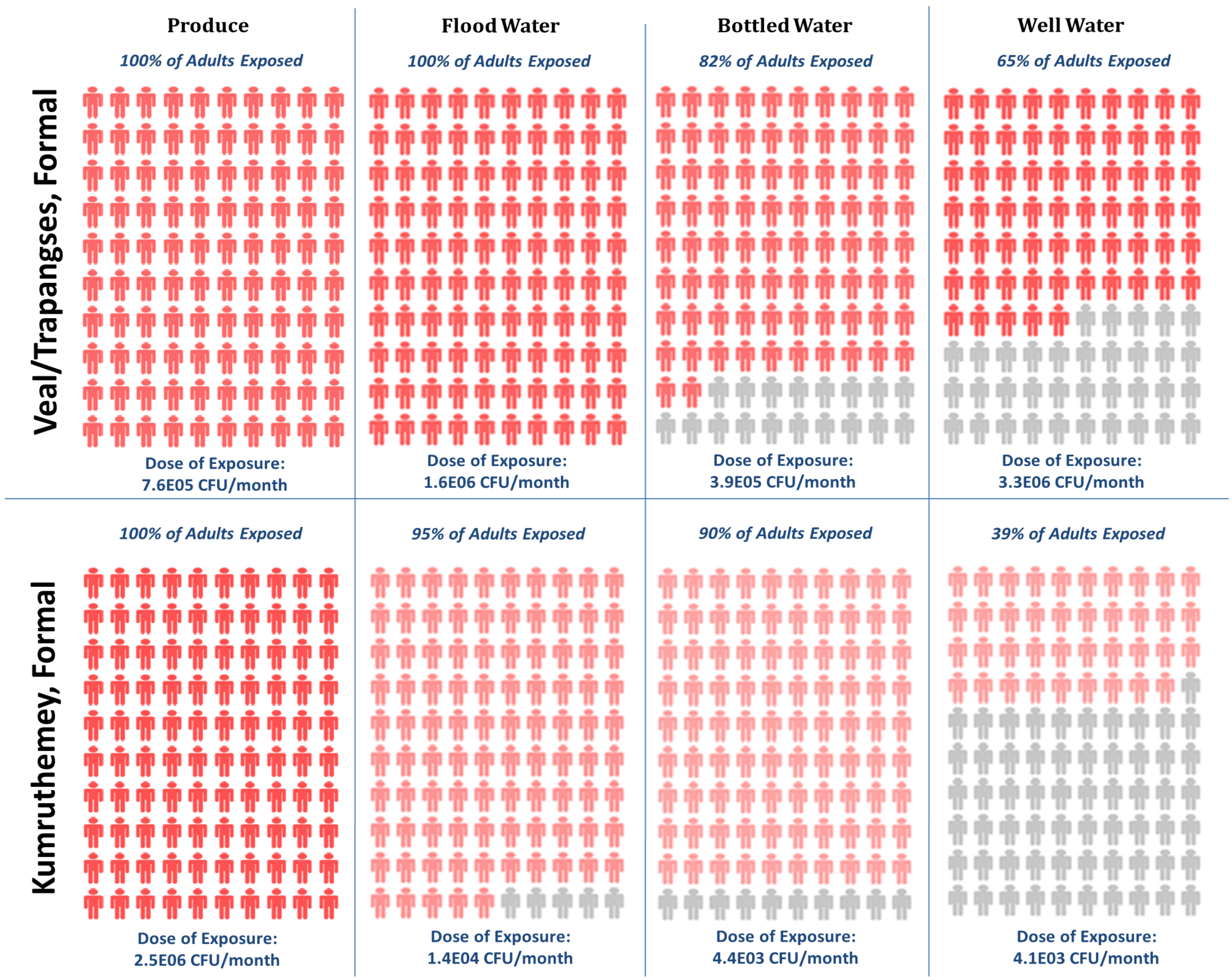


Figure 6: Fecal contamination risk profile of adults in the formal neighborhoods of Kumruthemey and Veal/Trapangses

Adults in Veal/Trapangses were exposed to more fecal contamination through floodwater, and bottled water. Furthermore, they were exposed to approximately 800 times more fecal contamination through drinking well water than adults in Kumruthemey. (Figure 6)

Fecal contamination of ice samples from Veal/Trapangses was higher than those from the formal Kumruthemey neighborhood [Mean (SD): 142.2 CFU/100mL (282.5) vs. 48.2 CFU/100mL (50.6)]. (Appendix B)

More children in Veal/Trapangses consumed produce, drank well water, and had contact with floodwater than in the formal Kumruthemey neighborhood. (Table 4) Children in Veal/Trapangses were exposed to greater levels of fecal contamination from floodwater, bottled water, and well water. Children in both neighborhoods were exposed to similar high doses of fecal contamination from raw produce. (Table 4)

Table 4: Percent exposed and monthly dose of *E. coli* estimated for children in the formal neighborhoods of Kumruthemey and Veal/Trapangses

	Kumruthemey (formal)		Veal/Trapangses	
Pathway	**Dose (*E. coli* CFU/month)**	**Percent Exposed**	**Dose (*E. coli* CFU/month)**	**Percent Exposed**
Produce	4.1E05	94	5.7E05	100
Floodwater	5.7E05	80	1.7E06	100
Bottled Water	2.8E03	70	1.2E05	61
Well Water	1.8E03	32	2.2E05	48

Typical home in an informal settlement in Siem Reap; note presence of floodwater surrounding homes

Environmental samples collected from study neighborhood during SaniPath assessment

Research Question 4:

What is the comparison of exposure to fecal contamination between formal neighborhoods that do not lie near an informal settlement?

To examine this question, SaniPath results from adults and children in Steung Thumey and Veal/ Trapangses two formal neighborhoods that were not near informal settlements, were compared. Raw produce was a dominant pathway for adults and children in both neighborhoods. (Table 7)

Flood water, bottled water, and well water were also dominant pathways for adults in Veal/ Trapangses. (Figure 7)

There was a considerable difference in exposure to fecal contamination through floodwater, as residents in Veal/Trapangses were exposed to over 3,000 times more fecal contamination from floodwater than adults in Steung Thumey. However, adults in Steung Thumey were exposed to a higher dose of fecal contamination via raw produce than those in Veal/Trapangses.

Another notable difference between these two neighborhoods is that only 16% of adults in Steung Thumey were exposed to fecal contamination from well water for drinking compared to 65% in Veal/Trapangses.

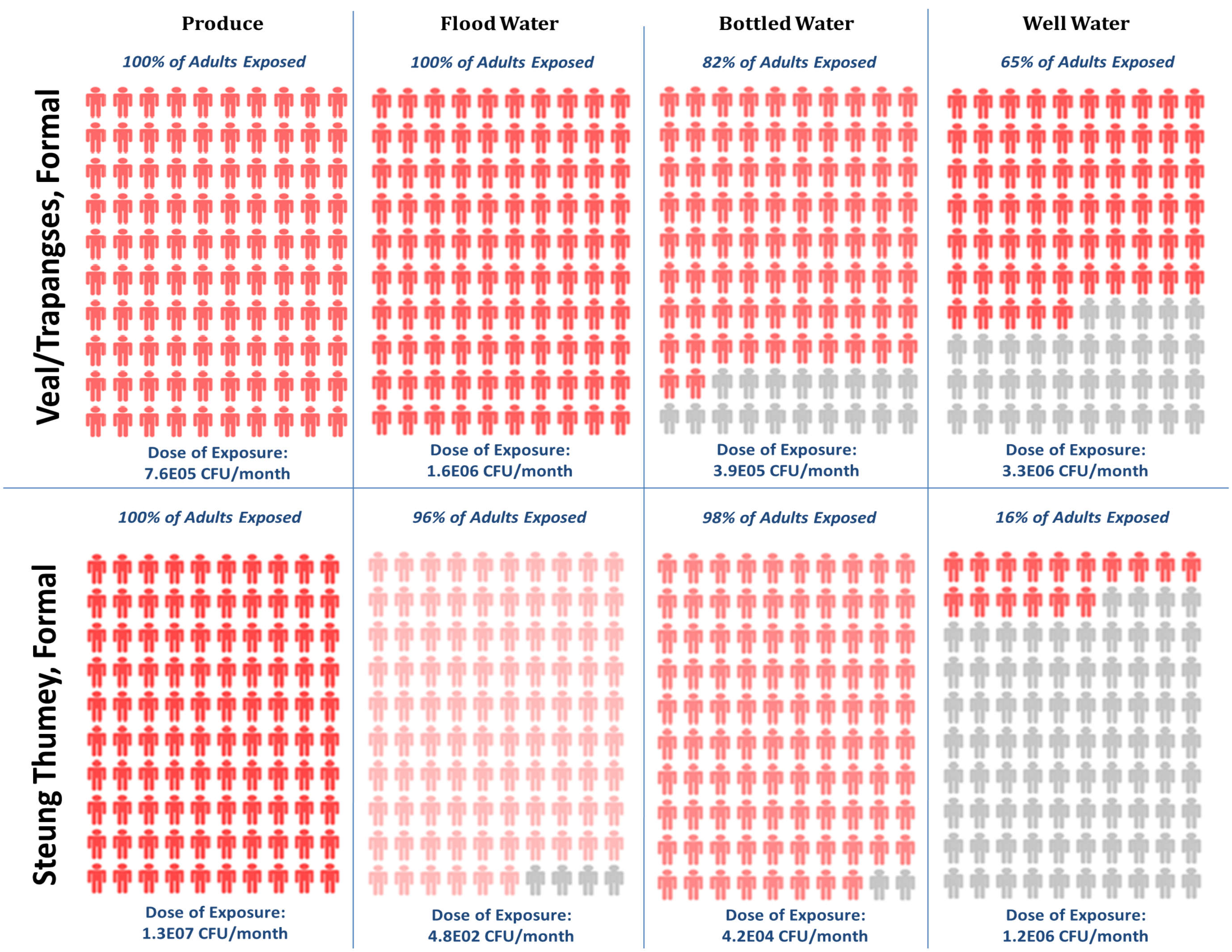


Figure 7: Fecal contamination risk profile of adults in the formal neighborhoods of Steung Thumey and Veal/Trapangses

Adult exposure to fecal contamination from drinking bottled water and drinking well water were similar in Veal/Trapangses and Steung Thumey. Of all the study sites, only residents in Steung Thumey had access to municipal water. However, because none of the respondents in Steung Thumey reported drinking municipal water, there was little to no risk of exposure to fecal contamination through drinking municipal water. Fecal contamination in ice samples from Veal/Trapangses was higher than samples from Steung Thumey [Mean (SD): 142.2 CFU/100mL (282.5) vs. 23.2 CFU/100mL (16.3)]. (Appendix B)

More children in Steung Thumey consumed produce, drank bottled water, and had contact with floodwater than in Veal/Trapangses. (Table 5) Children in Veal/Trapangses were exposed to greater levels of fecal contamination from floodwater, bottled water, and well water, while children in Steung Thumey were exposed to a higher concentration of *E. coli* from raw produce.

Table 5: Percent exposed and monthly dose of *E. coli* estimated for children in the formal neighborhoods of Steung Thumey and Veal/Trapangses

	Veal/Trapangses		Steung Thumey	
Pathway	**Dose (*E. coli* CFU/ month)**	**Percent Exposed**	**Dose (*E. coli* CFU/ month)**	**Percent Exposed**
Produce	5.7E05	94	2.6E07	100
Floodwater	1.7E06	80	8.1E03	92
Bottled Water	1.2E05	70	5.8E04	94
Well Water	2.2E05	32	5.3E04	11

Research Question 5:

What are the differences in exposure to fecal contamination between informal settlements?

Kumruthemey and Chong Kaosou informal settlements were compared to evaluate differences in risk of exposure to fecal contamination between two informal settlements (no land tenure) in different geographic areas. (Figure 8)

For adults and children in both informal settlements, the dominant pathways included raw produce (Table 7). In Kumruthemey, well water was also a dominant pathway for adults.

Adults in the Kumruthemey informal settlement were exposed to much higher levels of fecal contamination from well water than those in Chong Kaosou (8.7E05 CFU/month vs. 1.1E03 CFU/month). (Figure 8) Less than 50% of respondents in either neighborhood reported drinking well water, though adults in Kumruthemey drank more well water than those in Chong Kaosou (31% vs. 11%). Reported consumption of raw produce and reported contact with floodwater was greater than 90% in both neighborhoods.

Fecal contamination in ice samples from the informal settlement of Kumruthemey was higher than from the Chong Kaosou neighborhood [Mean (SD): 445.4 CFU/100mL (225.3) vs. 48.2 CFU/100mL (625.5)]. (Appendix B)

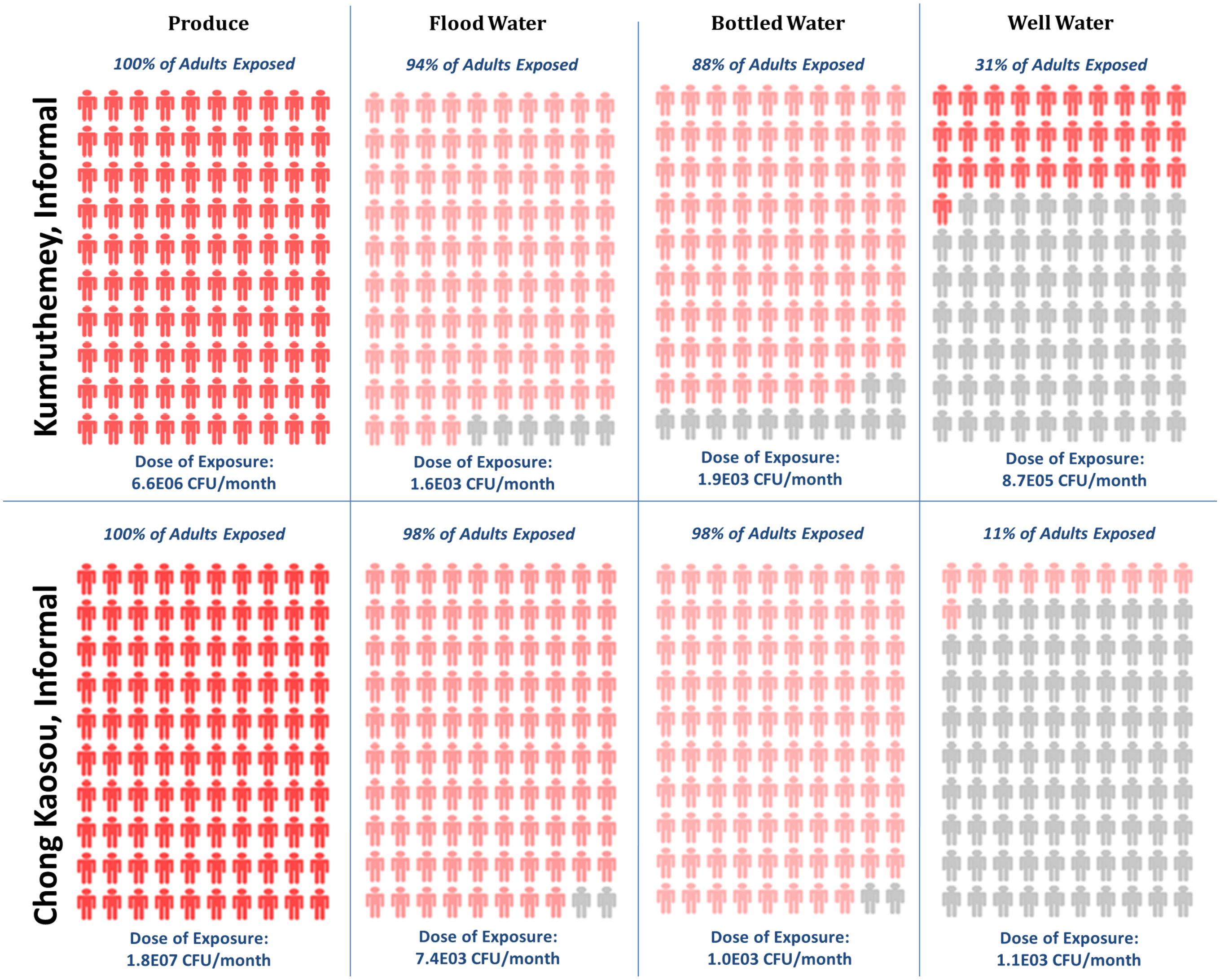


Figure 8: Risk profiles for adults in the informal neighborhoods of Kumruthemey and Chong Kaosou

The risks of *E. coli* exposure were similar for children in the two informal settlements of Kumruthemey and Chong Koasou. Only 8% of children in Chong Kaosou drank well water compared to 22% in Kumruthemey, informal.

Table 6: Percent exposed and monthly dose of *E. coli* experienced by children in the formal neighborhoods of informal Kumruthemey and Chong Kaosou

	Kumruthemey (informal)		Chong Kaosou (informal)	
Pathway	**Dose (*E. coli* CFU/month)**	**Percent Exposed**	**Dose (*E. coli* CFU/month)**	**Percent Exposed**
Produce	8.1E05	100	1.4E06	100
Floodwater	2.5E04	96	2.0E05	98
Bottled Water	1.2E03	62	3.5E02	73
Well Water	4.6E04	22	1.4E04	8

Dominant Pathways

The SaniPath team has developed an algorithm to identify dominant fecal exposure pathway(s) for each neighborhood and age group. The algorithm is based upon the proportion of the population exposed to those pathways and the corresponding magnitude of fecal contamination.

A dominant pathway of exposure to fecal contamination for adults and children in all neighborhoods was raw produce. (Table 7) In Steung Thumey and Chong Kaosou, produce was the only dominant pathway for both adults and children. By contrast, all pathways (produce, flood water, bottled water, and well water) were identified as dominant fecal exposure pathways for adults in the Veal/Trapangses neighborhood. In Veal/Trapangses, the dominant fecal exposure pathways identified for children were produce and flood water.

There were slight differences in risks of exposure to fecal contamination between the informal settlement and formal neighborhood of Kumruthemey. Dominant pathways for adults in the informal Kumruthemey settlement were produce and well water, but only produce was a dominant pathway in the formal Kumruthemey neighborhood. In the formal Kumruthemey neighborhood, a dominant pathway for children was floodwater, but this was not observed for children in the informal Kumruthemey settlement.

Bottled water was only a dominant pathway for adults in Veal/Trapangses but was not identified to be a dominant pathway in any other age group or neighborhood.

Table 7: Dominant pathways of exposure to fecal contamination in five neighborhoods in Siem Reap

Neighborhood	Adults	Children
Veal/Trapangses (formal)	Produce, Flood Water, Bottled Water, Well Water	Produce, Flood Water
Steung Thumey (formal)	Produce	Produce
Kumruthemey (formal)	Produce	Produce, Flood Water
Kumruthemey (informal)	Produce, Well Water	Produce
Chong Kaosou (informal)	Produce	Produce

Discussion

Informal settlements in Siem Reap are typically small in size and densely populated. The houses are often built on empty privately-owned land plots or on wide public roads alongside privately owned homes. This study examined whether land tenure status had an overall effect on residents' exposure to fecal contamination and whether exposure was higher for those living within or close to informal settlements compared to not living within or near an informal settlement.

It should be noted again that all the environmental samples were collected from the public domain and not at the household level. This was done because government interventions typically focus on improving public services and facilities and may not be able to influence household-level contamination. Therefore, data on household sanitation and hygiene practices were not collected or taken into consideration when generating the risk profiles. For example, it is possible that some people wash their produce before eating it raw, which, if washed adequately, would reduce the exposure to fecal contamination from produce. However, it is difficult to standardize the reduction in fecal contamination due to hygiene practices because of variability between individuals (i.e. one individual may thoroughly wash their raw produce, while another may not, thus resulting in a difference in the reduction of fecal contamination on the surface of produce). As such, the SaniPath exposure assessment may represent a "worst-case scenario" of risk of exposure to fecal contamination from the public domain. To understand exposure on a household level, further research would be required.

Key Findings

- Raw produce was a dominant pathway of exposure to fecal contamination in every study neighborhood, regardless of land tenure status
- The one neighborhood with a drainage system in the city center, Steung Thumey, had the lowest exposure to fecal contamination from floodwater amongst all study neighborhoods
- The primary and secondary source of drinking water for almost all survey respondents was bottled water and well water, both of which were contaminated with *E. coli*
- Samples of municipal water had very low *E. coli* contamination, yet none of the respondents reported this as a primary or secondary source of drinking water

Research Question 1:

What are the most important pathways of fecal exposure in the five selected neighborhoods in Siem Reap?

Produce was a major pathway of exposure to fecal contamination in the study neighborhoods in Siem Reap and attention should be given to address the contamination of produce. Frequently, produce from the same market will be consumed by residents from both high and low-income areas. The points of contamination are difficult to identify and therefore address. However, because produce was found to be a major source of exposure, additional investigation is warranted to better understand how and at what points produce becomes contaminated with human and/or animal feces.

While not necessarily a dominant pathway in all neighborhoods, a high percentage of survey respondents reported a high frequency of exposure to floodwater across all sites. Indeed, many residents reported that they experience flooding inside and surrounding their homes and cannot avoid contact with floodwaters during the rainy season. As previously mentioned, Steung Thumey is located in the city center where there are paved roads and drainage networks, and this infrastructure appears to mitigate the risk of exposure to floodwater. The SaniPath assessment did not collect data on duration of flood, depth of floodwater, or location of floodwater (i.e. in the road or within a compound). This information could be useful to better understand the extent of contact that individuals have with floodwater and how this may impact their health. While we did not collect behavioral data on ice consumption, we did find that in the informal neighborhoods, the ice was contaminated with high levels of *E. coli*.

Finally, the SaniPath assessment examined the risk of exposure to fecal contamination from multiple sources of drinking water, including well water, bottled water, and piped municipal water. While these sources were more contaminated than municipal water, bottled water and well water were almost always reported to be the primary and secondary sources of drinking water for residents across all neighborhoods. The SaniPath assessment did not measure *E. coli* in household water, but did ask residents if they treat their water prior to use. Less than half (44%) of the respondents reported that they treat their drinking water. We recommend increasing access to municipal water across the city including in informal settlements, promoting municipal water as a safe drinking source of water to ensure residents drink it once it is made available, regulations and oversight of municipal and bottled water quality, and encouraging residents to treat their drinking water before consumption.

Research Question 2:

What are the differences in exposure to fecal contamination between an informal settlement and a surrounding formal neighborhood?

The results from the Kumruthemey informal settlement and surrounding formal neighborhood showed that the exposure to fecal contamination from consuming raw produce, ingesting floodwater, and drinking bottled water were similar. This is logical because both neighborhoods purchase produce from the same markets and report eating raw produce at a similar frequency, both the informal and formal areas of this neighborhood share a geographic area and are prone to similar levels of flooding, and residents from both areas purchase bottled water at shops selling water this is bottled from all parts of the city.

The difference in exposure to fecal contamination between the two sites was primarily through the consumption of well water. The well water samples were more contaminated in the informal settlement. (Appendix B) The higher exposure from well water in the informal settlement may be due to poorly maintained or constructed wells that permit contamination from sewage or floodwater. Such high contamination of a primary drinking water source is of particular concern because people are directly ingesting this water on a daily basis. To reduce the risk of exposure from well water, further study of how well water becomes contaminated and methods of preventing contamination is required. Meanwhile, promoting effective water treatment at a community and household level can reduce the risk of exposure to fecal contamination and adverse health outcomes from consuming contaminated water. Ultimately, providing access to another source of safe drinking water may greatly reduce exposure through drinking water. The results of the current study have shown that the piped municipal water system has very low fecal contamination. Yet, only one study neighborhood had access to it, and it was not used as a primary or secondary drinking source.

Research Question 3:

Does proximity to an informal settlement affect risk of exposure to fecal contamination in a formal area?

The results from the Kumruthemey formal neighborhood (which borders an informal settlement) compared to the results from Veal/Trapangses (which does not border an informal settlement) show that there is great variation in exposure to fecal contamination between formal neighborhoods. The high risk of exposure from raw produce is comparable between the neighborhoods because the residents share common markets. However, for floodwater, bottled water, and well water, the results show a higher risk of exposure to fecal contamination in Veal/Trapangses. Because there exists large variation in exposure between formal neighborhoods and due to the current study design, it is difficult to conclude whether proximity to an informal settlement will increase the risk of fecal exposure from any given pathway. Rather, factors such as elevation, which may influence flooding; sources of bottled water; and quality and site of wells may be the primary determinants of the exposure to fecal contamination through these pathways.

Flooded street in Siem Reap

Research Question 4:

What is the comparison of exposure to fecal contamination between formal neighborhoods that do not lie near an informal settlement?

The results from Veal/Trapangses and Steung Thumey, both of which are formal neighborhoods that do not share borders with informal settlements, show notable differences in fecal exposure from all pathways. Steung Thumey is a middle-income neighborhood in the city center with a drainage system and paved roads, whereas Veal/Trapangses is a low-income neighborhood outside of the city center and lacks a drainage system. Residents in Veal/Trapangses were exposed to over 3,000 times higher dose of *E. coli* from floodwater than those in Steung Thumey. This may be due to the presence of a drainage system in Steung Thumey. While this may not be the only reason for the lower dose of exposure from floodwater, the presence of a drainage system allows excess water to be carried away from the neighborhood, decreasing the levels of contamination in stagnant water. The lower dose of exposure from floodwater in Steung Thumey provides evidence for the promotion of drainage networks, particularly in low-elevation areas of the city prone to flooding.

Residents in the middle-income neighborhood of Steung Thumey were exposed to a higher dose of *E. coli* than those in the low-income neighborhood. In this case, the produce samples in Steung Thumey had more contamination than samples in Veal/Trapangses. Multiple factors may influence the contamination of produce. The contamination may be a result of wastewater irrigation in the farm or garden, contaminated surfaces where produce is placed during transportation and in the markets, transfer of fecal matter from flies, and food handlers touching the produce with contaminated hands.

Another key finding from Steung Thumey is the low concentration of *E. coli* detected in piped municipal water. Municipal water samples were only collected in Steung Thumey, as this was the only study neighborhood with access to piped water. Though residents have access to this water in Steung Thumey, no respondents reported drinking the municipal water as their primary or secondary water source. Rather, people in Steung Thumey, as well as in all other neighborhoods, reported bottled water as their primary source of drinking water and well water as their secondary source. Anecdotally, people said they do not trust the safety of the municipal water and/or do not drink it because of lack of access. What is striking about this is that the samples of piped municipal water in Steung Thumey had very low *E. coli* contamination. Providing access to municipal water throughout the city and ensuring that it is safe to drink through routine water quality monitoring may make it a viable and favorable source of drinking water for residents of Siem Reap. City and community-level health messaging campaigns can educate people about the water safety to improve confidence and increase use of the municipal water.

Enumerator collecting produce sample at market

Research Question 5:

What are the differences in exposure to fecal contamination between informal settlements?

The results from the two informal settlements of Kumruthemey and Chong Kaosou showed a large difference in exposure to fecal contamination through the consumption of well water, with residents in Kumruthemey exposed to a much higher dose of *E. coli* than those in Chong Kaosou. This higher exposure is because of both higher frequency of consumption and higher concentration of contamination in Kumruthemey. Again, providing access to alternative sources of safe drinking water, improving quality of wells, and promoting water treatment are ways to prevent exposure to fecal contamination from drinking water.

Strengths and Limitations

The primary strength of the SaniPath exposure assessment is that the results focus on the measurement of risk rather than risk perception and relies on primary data—both behavioral surveys and microbiological analysis of environmental samples. The tool can be adapted to different cultural contexts, employs mobile data collection, and provides automated data analyses and data visualization. In addition, the unique risk profiles provide information for decision making in a format that is easy to understand by a variety of audiences.

However, this exposure assessment does have limitations. The assessment was conducted over a two-month period and is not able to capture temporal and seasonal variability in environmental contamination or behaviors. Furthermore, the information is only a snapshot of exposure at the neighborhood level and may not be generalizable to the entire city. This assessment also relies on self-reported information about behavior that may be biased due to

Recommendations

- **Raw Produce**
  - ◊ Investigate how and at what point produce is exposed to fecal contamination
  - ◊ Promote handwashing among market vendors and produce washing among residents
- **Floodwater**
  - ◊ Increase and maintain street drainage systems, especially in low-elevation areas to reduce contact with floodwater
- **Bottled Water**
  - ◊ Improve standards and regulations for bottled water quality
  - ◊ Encourage household water treatment of bottled water
- **Well Water**
  - ◊ Reduce fecal contamination of wells through improved well construction and maintenance
  - ◊ Encourage household treatment of well water for drinking
- **Municipal Water**
  - ◊ Improve access to municipal water and promote as safe source of drinking water
  - ◊ Conduct routine water quality testing to ensure drinking safety
- **Ice**
  - ◊ Educate public about contamination of ice and encourage using treated water for making ice
  - ◊ Improve standards and enforcement through routine monitoring of ice quality

social desirability or due to adults either over- or underestimating the frequency of specific behaviors of children.

In addition, there were challenges with the study sites. Because most of the selected study neighborhoods had less 100 households, we were not able to conduct the full 100 household surveys recommended in the tool. Municipal water was only accessible in one neighborhood thus limiting the sample size for this particular pathway. In addition, the environmental samples were only taken from public areas and household level samples and risk of exposure are not measured. Household or individual level hygiene, or other risk-mitigating behaviors (such as household water treatment) are not considered in the risk profiles in this report.

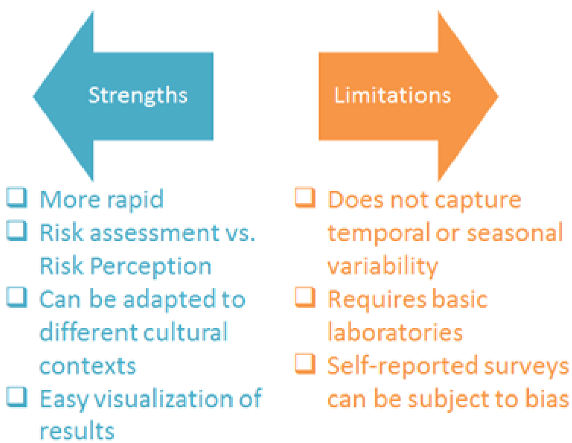


Figure 9: Strengths and limitations of SaniPath Exposure Assessment Tool

Acknowledgements

The success of this project was made possible through close collaboration with Cambodian national and regional partners. WaterAid Cambodia worked with the SaniPath team to develop the study design and implement the project. Water for Cambodia in Siem Reap provided laboratory facilities and experienced laboratory technicians to conduct all of the environmental sample analyses. The Community Engagement and Development Team (CEDT) provided guidance and resources with regards to informal settlements in Siem Reap. Finally, this project could not have been possible without the support from the Cambodian Ministry of Public Works and Transport, who advised on site selection, provided city resources, and participated in all of the SaniPath data collection.

References:

1. Fukuzawa, M (2014). The Phnom Penh Rental Housing Survey: A Study on Urban Poor Rental Housing in Phnom Penh. Retrieved from https://kh.boell.org/sites/default/files/stt-rental-housing-survey_2014_final.pdf

2. K Seshimo. (2004). Infrastructure assessment in the context of rapid urbanization: The Case of Cambodia. Engineering, Construction and Operations in Challenging Environments: Earth and Space 2004, p.735-742 http://www.murdocksolon.com/pdf/MSA_CambodiaInfrastructure.pdf

3. WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation. (2015). Cambodia: estimates on the use of water sources and sanitation facilities (1980-2015). www.wssinfo.org/documents/?tx_displaycontroller[type]=country_files

4. WaterAid Cambodia. (2015). Water, Sanitation and Hygiene (WASH) situation and issues for urban poor people and vulnerable groups, Cambodia. *A Review Prepared by WaterAid Cambodia.*

5. Pruss-Unstun, A, Bos, R, Gore, F, and Bartram, J. (2008). Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health. World Health Organization, Geneva

6. National Institute of Statistics/Cambodia, Directorate General for Health/Cambodia, and ICF International. (2015). Cambodia Demographic and Health Survey 2014. Phnom Penh, Cambodia: National Institute of Statistics/Cambodia, Directorate General for Health/Cambodia, and ICF International. Retrieved from https://dhsprogram.com/pubs/pdf/fr312/fr312.pdf

7. Chandara, S. (2016, January 6) Angkor visitor numbers flat in 2015. *The Phnom Penh Post*. Retrieved from http://www.phnompenhpost.com/business/angkor-visitor-numbers-flat-2015

8. National Institute of Statistics. (2008). General Population Census of Cambodia 2008. Retrieved from http://www.stat.go.jp/english/info/meetings/cambodia/pdf/pre_rep1.pdf