**Distribution Agreement**

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, now or hereafter known, including display on the world wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature:

_____ _____

Zimo Z. Banta Date

Behaviors, Conditions, and Child Hand Contamination Among Children and Caregivers in Peri-Urban Households in Accra, Ghana

By

Zimo Z. Banta
Master of Public Health

Global Epidemiology

---

Matthew C. Freeman, MPH PhD
Committee Chair

# Behaviors, Conditions, and Child Hand Contamination Among Children and Caregivers in Peri-Urban Households in Accra, Ghana

By

Zimo Z. Banta

B.A.
Yale University
2007

Thesis Committee Chair: Matthew C. Freeman, MPH PhD

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Global Epidemiology
2015

## Abstract

Behaviors, Conditions, and Child Hand Contamination Among Children and Caregivers in Peri-Urban Households in Accra, Ghana

By Zimo Z. Banta

Exposure to fecal pathogens can result in enteric diseases such as diarrhea and soil-transmitted helminth (STH) infection, creating a heavy disease burden particularly among children under five years of age. These diseases can be mitigated by improvements in infrastructure and behaviors that address major enteric pathogen transmission pathways. In poor urban areas, a confluence of transmission pathways appear in the form of overcrowding, poverty, water contamination, and lack of sanitation infrastructure to heighten the risk of exposure. Few studies exist on the link between behaviors and exposure to fecal pathogens, particularly in low-income urban or peri-urban environments and among children under five years of age, the population most vulnerable to enteric diseases and their health repercussions.

This study quantified observed behaviors of children under five years of age and their caregivers in Accra, Ghana and assessed their relationship with household conditions and child hand contamination. We observed numerous opportunities for fecal hand contamination, which were rarely intercepted by hygiene behaviors, signaling frequent contamination risks in the household environment. We found a weak association between the frequency of child bathing events and enterococci concentration on children's hands, suggesting that increasing child bathing could be investigated as a way to decrease child hand contamination. We also found a serious lack of sanitation and hygiene infrastructure, which could be a major barrier to improving hygiene behaviors and decreasing exposures to fecal contamination in urban and peri-urban households.

# Behaviors, Conditions, and Child Hand Contamination Among Children and Caregivers in Peri-Urban Households in Accra, Ghana

By

Zimo Z. Banta

B.A.
Yale University
2007

Thesis Committee Chair: Matthew C. Freeman, MPH PhD

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Global Epidemiology
2015

Acknowledgements

I would like to thank Matthew Freeman, my thesis advisor, for introducing me to the SaniPath study and for providing me with such excellent guidance throughout the entire thesis process. I would also like to thank Christine Moe for the opportunity to work with the dataset. Thank you also to Clair Null, for the constructive feedback throughout the revision process. I would like to thank the Center for Global Safe Water SaniPath study staff – Kate Robb, Andrew (Yuke) Wang, and Habib Yakubu – for all the support, patience, and detailed feedback to all of my questions along the way.

I would like to thank all of my professors at the Rollins School of Public Health, for teaching me the analytical skills I needed for my thesis and for enhancing my critical thinking for my career and life. Thank you also to my ADAP, Jena Black, for providing me with invaluable educational and professional guidance and counseling.

Finally, I would like to thank my friends and family for providing me with unwavering support. In particular, I would like to thank my mother, Liu Yuan, for always being there for me and loving me unconditionally. I would like to thank my husband, Justin Banta, for believing in me and walking with me, not only throughout this thesis process but also through life.

Table of Contents

**Introduction**

Exposure to fecal pathogens can result in enteric diseases such as diarrhea (Vasco *et al.*, 2014; Gomes *et al.*, 1991; Guerrant *et al.*, 1990) and soil-transmitted helminth (STH) infections (Davis *et al.*, 2014; Brown, Raff, & Hotez, 2009), which together accounted for an estimated 1.5 million deaths and almost 105 million DALYs in 2012 (WHO, 2014). Diarrhea alone is the second leading infectious cause of death worldwide for children under five years of age, causing approximate one in ten child deaths and contributing an estimated 0.7 million deaths in 2011 (Liu *et al.*, 2012; Walker *et al.*, 2013). Sub-clinical infection at a young age may also result in a condition known as tropical enteropathy (Humphrey, 2009) that may result in stunting (Dangour *et al.*, 2013).

These adverse sequelea can be mitigated by improvements in infrastructure and behaviors that address major enteric pathogen transmission pathways such as water, food, hygiene, personal contact, and sanitation. Inadequate water, sanitation, and hygiene (WASH) caused an estimated 842,000 deaths worldwide in 2012, representing 1.5% of the global disease burden and 5.5% of the disease burden among children under five years old (Prüss-Ustün *et al.*, 2014). WASH access and practices can reduce the odds of STH infection by at least 33% and prevent 58% of diarrheal diseases (Strunz *et al.*, 2014; Prüss-Ustün *et al.*, 2014).

Sanitation facilities play an important but complex role in diarrhea risk and fecal contamination in the household. Reported use of an improved toilet was associated with lower fecal streptococci contamination on caregiver and child hands in Tanzanian households (Pickering *et al.*, 2010) and with a 1.7-fold decrease in *E. coli* virulence genes in household stored drinking water (Mattioli *et al.*, 2014). In Bangladesh, improved sanitation facility and no visible feces in or around the household were associated with lower fecal

coliform contamination on household toys (Vujcic *et al.*, 2014). However, in peri-urban Tanzania, the presence of a concrete slab, which confers the improved sanitation status to pit latrines, was not significantly associated with the level of indicator bacteria (*E. coli* and enterococci) in household soil samples (Pickering *et al.*, 2012). In Kenya, students that received a sanitation improvement in their school had higher rates of fecal pathogens on their hands compared to those that did not, perhaps due to poor handwashing and latrine cleaning practices (Greene *et al.*, 2012). Further, evidence from a latrine promotion and construction program in India revealed that increased latrine coverage did not significantly decrease either reported diarrhea prevalence in children under five or fecal contamination of stored household water, wells, hands of mothers and children, and sentinel toys (Clasen *et al.*, 2014). This lack of association could have been due to insufficient community-level latrine coverage or latrine underuse. After all, the presence of latrines, regardless of improved status, does not guarantee use of the latrines (Kwiringira *et al.*, 2014). However, it is also feasible that fecal contamination occurred mainly through other exposure pathways unmediated by latrines, such as anal cleansing behaviors, food production and preparation, and handwashing (Clasen *et al.*, 2014).

Hygiene behaviors also play a critical role in the transmission of enteric pathogens. Inadequate hygiene behaviors of children and their caregivers, such as eating unwashed raw vegetables and not washing hands before eating or after defecation, are associated with more than twice the risk of diarrhea in children under five and two years of age compared to positive hygiene behaviors (Strina *et al.*, 2003; Gorter *et al.*, 1998). Handwashing with soap has been found to decrease risk of diarrheal disease by 23% to 40% (Freeman *et al.*, 2014). The association between inadequate hygiene behaviors and diarrheal disease could be explained by an increased exposure to enteric pathogens that caregivers and children

experience upon exhibiting these behaviors. In the household environment specifically, a wide range of activities including preparing food, dishwashing, and bathing have been found to be associated with increased fecal indicator bacteria on hands of mothers in Tanzania, suggesting widespread fecal contamination and multiple exposure pathways in the household (Pickering *et al.*, 2011; Mattioli *et al.*, 2014). In addition, fecal streptococci contamination on hands has been found to be associated with increased self-reported gastrointestinal symptoms in Tanzanian households (Pickering *et al.*, 2010).

While transmission of enteric pathogens can occur through WASH-related pathways, larger systemic factors such as socioeconomic inequality and gender inequality are also correlated with transmission (Eisenberg *et al.*, 2012). In poor urban areas, a confluence of these pathways appear in the form of overcrowding, poverty, water contamination, and lack of sanitation infrastructure to heighten the risk of exposure to infectious diseases like diarrheal and intestinal parasitic diseases (WHO, 2010; Crompton & Savioli, 1993). In the Republic of Congo, the odds of reported diarrheal disease were found to be 3.5 times greater for urban children compared to rural children (Mock *et al.*, 1993). In a cross-sectional study of children in two geographically and socioeconomically comparable communities in Malawi, one urban and one rural, prevalence of helminth infection was significantly higher among the urban children, and urban location was the most significant risk factor for helminth infection, after controlling for age, sex, and socioeconomic status (Phiri *et al.*, 2000).

In Ghana, estimates of improved water coverage range from 57% to 82%, and only 13% of the population has access to improved sanitation (World Bank, 2011). About one fifth of the population practices open defecation, which presents a major challenge for controlling the spread of enteric diseases. Among infectious diseases, diarrhea was the third

leading cause of death among Ghanaian children under five years old, causing almost one in ten deaths in the age range in 2008 (Black *et al.*, 2010).

Although water supply and sanitation coverage are higher in urban areas than rural areas of Ghana (water supply: 58% vs. 57% respectively; sanitation: 18% vs. 7% respectively), WASH infrastructure in urban areas is not keeping apace of population growth (World Bank, 2011). In fact, urban safe water coverage decreased from 76% in 1990 to 60% in 2002 due to the rapid rise in population (Awuah, E., Nyarko, K.B., Owusu, P.A., 2009). Further, significant differences exist between the urban poor and the urban rich in terms of access to water and sanitation facilities and diarrhea outcomes (Boadi & Kuitunen, 2005). In Accra, wealthier households had much greater access to a safe water source and to sanitation facilities compared to poorer households, and access to water and sanitation were both inversely associated with reported incidence of childhood diarrhea (Boadi & Kuitunen, 2005).

A possible explanation for the relationship between access to water and sanitation and lower diarrhea incidence is that access to infrastructure facilitates proper hygiene and sanitation behaviors, which reduces the transmission of fecal pathogens that cause diarrhea. Indeed, evidence exists that the built environment can mediate hygiene behavior in the household. In Kyrgyzstan, the presence of a washstand (defined as "essentially a small tank with a tap, positioned over a basin that drains into a bucket below") was associated with handwashing after latrine use (Biran *et al.*, 2005). In Bangladesh, the presence of water and soap was associated with twice the odds of handwashing after fecal contact (Luby *et al.*, 2009). Further, hygiene behaviors of caregivers were associated with lower child diarrhea incidence in Bangladesh (Alam *et al.*, 1989). However, few studies exist on the link between

behaviors and exposure to fecal pathogens, particular among children under five years of age – the population most vulnerable to enteric diseases and their health repercussions.

Many studies have explored household hygiene behaviors, but they have mainly focused on handwashing with soap among caregivers and children (Luby *et al.*, 2009; Schmidt *et al.*, 2009; Aunger *et al.*, 2010). A limited number of studies have observed child defecation and stool disposal behaviors (Biran *et al.*, 2005, Curtis *et al.*, 2001), food hygiene, and general domestic hygiene (Gorter *et al.*, 1998). Those studies have mainly examined the factors influencing handwashing behavior, the effect of handwashing behavior on diarrhea, or a program's impact on hygiene behavior. Moreover, few observational studies of child hygiene behaviors exist. The majority of studies on hygiene behavior are of caretaker behaviors or caretaker-reported child behaviors (Traoré *et al.*, 1994; Knight *et al.*, 1992; Mertens *et al.*, 1992; Yearger *et al.*, 1999).

This study presents evidence on the role of behaviors and household conditions in potential exposure to fecal pathogens. To our knowledge, this is one of the first studies conducted in low-income urban or peri-urban environments to use structured observation to quantify and describe a wide range of hygiene behaviors for children under five and their caregivers and to link these behaviors to child hand contamination. We quantify these behaviors and assess their relationship with the household environment and exposure.

## Methods

### *Background*

This study was nested within a study known as SaniPath, whose goal is to use an interdisciplinary approach to explore the pathways of enteric pathogen transmission in low-

income urban environments. In 2012, observational data on behaviors of children under five years of age and their caregivers, microbiological data, and survey data on household characteristics and conditions were collected from households in four neighborhoods in Accra, Ghana. The neighborhoods - Alajo, Bukom, Old Fadama, and Shiabu - were included in this study to capture variability in settlement type (squatter vs. formal), location (inland vs. coastal), susceptibility to flooding, proximity to a major market, and mixed-income status (Peprah *et al.*, *unpublished paper*)

Enumerators were recruited by the local research partner, TREND Group, and trained in a classroom setting and in field pilots on ethical conduct of research, structured observation, and administration of household surveys. TREND Group and community liaisons supervised enumerators during the data collection process.

### *Ethics*

Ethics approval was obtained from Institutional Review Boards at Emory University (Atlanta, USA) and the Noguchi Memorial Institute for Medical Research (Accra, Ghana). Consent was obtained from all adult (defined as 12 years and older) participants prior to data collection. For participants younger than 12 years, consent was obtained from parents.

### *Study design and enrollment*

A structured observation tool was developed to measure the behaviors that put children under five years of age and adult caregivers in contact with fecal contamination in the household and the frequency and duration of those behaviors. The initial version of the tool was informed through a literature review and unstructured observation in two urban neighborhoods in Accra that were similar to but were not the study neighborhoods. In

February 2012, one month before data collection, enumerators piloted the tool for one week in the study neighborhoods. The households involved in the pilot were excluded from the study. The study team incorporated changes from the pilot into the final tool.

Households were eligible for inclusion in structured observation if there was at least one child under five years of age who was in good health, defined as no fever or malaria, in the household. A household was defined as a group of people that cooked and lived together. Households were chosen from among eligible households recommended by community liaisons to achieve variation in household sanitation options and the level of mobility among the children.

Researchers conducted structured observations and microbiological sampling in households from March to August 2012. Each Friday, neighborhood liaisons purposively selected ten households to participate. TREND senior staff and enumerators confirmed participation with six to eight of the selected households, by obtaining informed consent from as many adult females as possible in each compound and scheduling a 6-hour structured observation session for the following week. A compound was defined as a living quarter with two or more households, and households in a compound tended to be related family members. Enumerators scheduled households for observations either from 6:00 am to 12:00 pm noon or from 12:00 pm noon to 6:00 pm, based on when heads of household expected to be available. Researchers observed at least six households every week in each neighborhood. The number of households selected for observation was based on maximizing sample size within budget and time constraints.

On the day of the structured observation, the names of all consenting adult females in the selected compound were written on pieces of paper, and one name was randomly drawn from a hat to be the person with whom the observation would begin. Each eligible

child of the sampled female was assigned a number starting from 1, each number was written on a piece of paper, and one paper was randomly drawn from a hat. The child corresponding to the number drawn was the child to be observed. One enumerator observed the child and caregiver for six hours. The enumerator located themselves in unobtrusive common compound areas where key behaviors could be observed. They attempted to observe the same caregiver and child over the entire observation period. However, if a child was out of sight for longer than one hour or a caregiver left the compound with the child, the enumerator switched to another child for observation and noted the change on the data collection form. In the final hour of data collection, enumerators obtained consent from and conducted a household conditions survey with the most knowledgeable adult in the compound. Also in the final hour, microbial data collectors went to each household to collect hand rinse, swab, water, soil, and/or food samples. Observation ended after the completion of the microbial sample collection.

### *Structured observation*

Enumerators noted the start time, nature, and location of child behaviors every time that they were observed, including playing/sitting, sleeping, and key behaviors such as handwashing, bathing, defecating, and eating. Locations of interest included on unimproved ground (dirt), improved ground (floor), off the ground (i.e. with the caregiver or in a chair), in a sewage water and trash area (SWATA), or in a drain. Drains are largely uncovered gutters lining the sides of streets that serve to syphon rainwater and prevent flooding. They were a location of interest because they can be highly contaminated with trash and fecal matter and flood regularly due to clogging or lack of drainage (Null & Peprah, 2013; SaniPath, *unpublished data*; Bali, 2013). Enumerators recorded tallies of the number of times

the child touched other children, touched other adults, put fingers in the mouth, and put objects in the mouth. Simultaneously occurring behaviors were recorded in separate boxes on the observation sheet but with the same start time. The enumerators also recorded the start time and occurrence of caregiver behaviors, including handwashing, handling food, sullage disposal, latrine use, handling money, and sweeping.

### *Household conditions survey*

Upon completion of the structured observation, enumerators obtained verbal consent to conduct a household conditions survey. The survey was a structured interview that included questions about household demographics, water supply and handling practices, sanitation and hygiene practices, child health, and sanitation and hygiene facility characteristics.

### *Microbiological data*

While enumerators conducted the household conditions survey during the final hour of observation, microbial data collectors collected hand rinse, swab, water, soil, and/or food samples. The data collectors took samples of items and surfaces that enumerators reported to have had frequent contact with the children during the structured observation. They collected hand rinse, swab, and food samples at critical times in the fecal-oral transmission route, such as before food preparation and before feeding the child. Due to logistical and laboratory processing constraints, microbial data were collected only from households observed on weekdays and in the 6:00 am to 12:00 pm noon period.

Microbial data collectors obtained consent from each participant before collecting a hand rinse sample. Any visible dirt on the participant's finger pads, palm, or nails was noted.

Wearing gloves sterilized using alcohol, data collectors submerged each participant's hands up to the wrist in 500 ml sterile phosphate buffered saline, pH 7.2 solution in a Whirl-Pack bag for 30 seconds per hand. Samples were transported to the laboratory within six hours of collection and stored in a 4°C refrigerator. *E. coli* and enterococci assays were performed using $10^0$, $10^1$, $10^2$ ml raw samples. Samples were tested for *E. coli* using membrane filtration with MI Agar, and enterococci samples were tested using membrane filtration with mEI Agar.

### *Measurements*

We used principal component analysis to create asset ownership quintiles. Missing values of asset questions were imputed with mean neighborhood values. We quantified the frequency of key behaviors of interest for caregivers and children (such as handwashing or defecation events) by calculating the number of events per person-hour observed for each caregiver or child, then computing the mean or median among all the caregivers or children. We reported these results in terms of events per ten person-hours observed because many events were rare.

Caregiver handwashing opportunities were defined as before preparing or handling food, after preparing or handling food – which is associated with higher hand contamination (Pickering *et al.*, 2011), after cleaning child's bottom, after sullage disposal, after using the latrine, after handling money, and after sweeping. Although enumerators did not note cleaning child's bottom as a caregiver key behavior, they noted whether the child's bottom was cleaned after a child defecation event; for instances where the child's bottom was cleaned, the time of the child defecation event was used as the time the caregiver cleaned the child's bottom. Caregivers fulfilled handwashing opportunities if they washed hands

immediately following (or prior to) the handwashing opportunity. Caregivers without any observed handwashing opportunities were considered to have zero unfulfilled caregiver handwashing opportunities.

Child hygiene opportunities included after defecation and before eating. Children fulfilled hygiene opportunities if they washed hands or bathed immediately following defecation or washed hands immediately before eating. We calculated the proportion of child defecation events not followed by a child bathing or handwashing event and the proportion of child defecation events where the child's bottom was not cleaned. Children without an observed defecation event were considered to have a zero proportion of defecation events not followed by bathing, handwashing, or cleaning bottom.

We calculated the proportion of time that children spent in unclean locations; unclean locations were defined as on unimproved ground (dirt), in SWATA, or in a drain, and clean locations were defined as on improved ground (floor) or off the ground (such as with a caregiver or on a chair). We also measured the proportion of child defecation events where child feces were disposed improperly. We defined improper disposal as placing feces in a drain or leaving them on the ground and proper disposal as placing feces in a latrine or trash, assuming that feces placed in trash would be sufficiently isolated to prevent further contact between the feces and the residents of the household disposing of the feces.

Hand contamination of caregivers and children under five years was measured by concentrations of *E. coli* and enterococci from handrinses. We used the $\log_{10}$ of these concentrations for analysis.

### *Analysis*

We conducted one six-hour behavioral observation visit for most households, although twelve households were observed twice. The household conditions survey was administered during the first time that these households were observed. Eleven households were observed once in the afternoon timeslot, then again the following morning to assess reactivity. One household was observed twice in the morning. For these twelve households, we analyzed only one observation visit's data, giving preference to the visit that had accompanying microbial data. In one household, microbial data was collected during both of its observation visits; we used the observation visit that had more accompanying microbial data points. Another household did not have microbial data accompanying either of its two observations; we chose the observation visit that occurred the same day as when the household conditions survey was conducted.

Descriptive analyses were performed for demographic characteristics, stratified by neighborhood. Means and medians were calculated for continuous data. Using simple linear regression, we performed bivariate analysis of the effect of caretaker behaviors, behaviors of children under five years, and household conditions on hand contamination among children under five years. We chose behaviors and conditions that we believed to be most likely associated with child hand contamination.

More specifically, in the bivariate analysis we examined the frequency of caregiver handwashing events and proportion of caregiver handwashing opportunities that were unfulfilled by handwashing in order to explore the relationship between caregiver hand hygiene and child hand contamination. We explored the relationship between child hygiene behavior and child hand contamination by examining the frequency of child handwashing

and bathing events and the proportion of child defecation events not followed by handwashing, bathing, or cleaning the child's bottom.

We also examined the relationship between child hand contamination and a child's physical location and mobility level. We assessed the relationship between fecal contamination in the larger household environment and child hand contamination by examining the proportion of child defecation events where feces were improperly disposed and whether feces were visible around compound grounds. The effect of the presence of a sanitation facility in the compound on child hand contamination was also assessed. Whether a household ran a business from the household or compound was thought to contribute to child hand contamination, because a business would likely increase the number of contacts with other people and therefore increase contamination in the larger household environment. Finally, we assessed the association between child hand contamination and potential confounders, including child age, sex, wealth quintile, and neighborhood.

We conducted a multiple linear regression including all of the behaviors and household conditions that were in the bivariate analysis, controlling for child age, sex, wealth quintile, and neighborhood. We assessed the interaction between the proportion of time spent in unclean locations and child mobility level. All analyses were performed using SAS 9.4 (Cary, NC).

## Results

### *Demographics*

A total of 117 households responded to the household conditions survey (Table 1). The majority of respondents were female non-heads of household.

The majority of households in all four neighborhoods reported having electricity and running a business from their house; half of the businesses were vending prepared food. The majority in Alajo, Bukom, and Shiabu was Christian whereas the majority was Muslim in Old Fadama.

The majority of study households reported completing some or all of primary school, followed by no formal education and by at least secondary school. Education attainment was lowest in Old Fadama, where the majority reported no formal education, followed by some or all of primary school, then by at least secondary school.

The majority of households overall and in each neighborhood reported sachets as their primary source of drinking water and the tap from a piped network as their only source of water for cooking and hygiene. Only 9.6% of households had a latrine on the compound. Alajo had the highest proportion of households with latrines on the compound, followed by Shiabu and Bukom; none of the households in Old Fadama reported having latrines on the compound. No households reported having a private household latrine that they did not need to share with any other households. Among households with a latrine on the compound, households shared with a median of 7.7 households (range 2.0 – 16.0). No households had a handwashing station. The median spent per day on public latrines and drinking water was greater than C$0.00 cedis.

Old Fadama was the poorest neighborhood, with a larger proportion of households in the poorest quintiles and a lower proportion in the richer quintiles; Alajo was the least poor neighborhood. Shiabu had the greatest wealth disparity, with a small middle quintile. These trends tracked well with the settlement type of the neighborhoods: Old Fadama was squatter settlement, Shiabu was a mixed-income formal-squatter, and Alajo and Bukom were formal settlements.

### *Reported defecation behaviors*

Table 2 presents the responses of participants in the household conditions survey to the question on the typical defecation location of various groups of people in their household. Participants most frequently reported that male and female adults typically defecate in public latrines, followed by compound latrines and bags or flying toilets. For children ages 5 to 12, participants most frequently reported defecation in public latrines (55%), followed by bags or flying toilets (15%), chamber pots (12%), compound latrines (10%), and outside (4%). Observations of children under 5 years of age showed that when defecation events occurred in bags and on the ground, child feces were not disposed in latrines; the only time when feces were disposed in a latrine was when defecation occurred in a potty or chamber pot, and only 11% of those events resulted in latrine disposal. Therefore, unless the child defecated in a latrine, child feces were unlikely to go into a latrine. Based on this information, we can deduce that for 35% of children ages 5 to 12, the final destination of child feces was likely not in a latrine.

### *Observed caregiver behaviors*

Observational data were collected on a total of 108 caregivers from 101 households (Table 3). The most frequently observed caregiver behavior was preparing or handling food, 9.1% of which were preceded by handwashing and 7.7% were followed by handwashing. Handling money was the second most frequently observed, and only 4.1% of these events were followed by handwashing. Sullage disposal, sweeping, and cleaning child's bottom were less frequently, and a low proportion was followed by handwashing. Only two latrine use events were observed among caregivers, both of which were followed by handwashing. The

mean number of handwashing events per 10 p-hrs observed was 0.97 (SD 2.15), with 33.3% of the events using soap.

### *Observed child behaviors*

Observational data were collected on a total of 117 children, 52 boys and 64 girls, with one child missing gender information (Tables 4a-b). Children were observed to have frequent contact with other children and adults, and to frequently have fingers and objects in their mouths. Older children had more frequent contact with other children and less frequent mouthing of objects. Compared to girls, boys were observed to have more frequent contact with other children and with adults. On the other hand, girls more frequently put fingers and objects in their mouths.

Only 10 total child handwashing events were observed. Only one child handwashing event used soap, which was observed for a boy 1-2 years old. No handwashing events were observed among children <1 year old, and handwashing occurred slightly more frequently among children >2 years old compared to children 1-2 years old. Handwashing occurred slightly more frequently among boys than girls.

Child bathing events were more numerous than handwashing, with a total of 58 events observed, but were still rare enough that median events per 10 p-hrs was 0.00 for all age and sex groups except for boys. The majority (75.4%) of bathing events used soap. Bathing events occurred slightly more frequently among children >2 years of age compared to other age groups and among boys compared to girls. Soap use was slightly more frequent among girls than boys. The majority of bathing events (86.2%) were observed before 12:00pm noon; in fact, the majority (69.0%) bathing events occurred in the early morning, before nine am.

A total of 41 defecation events were observed, 17.1% of which were followed by child handwashing or bathing, but only 9.8% of which were followed by child handwashing or bathing *with soap*. Girls had a higher proportion of defecation events followed by handwashing or bathing and by handwashing or bathing with soap. The child's bottom was cleaned in the majority (92.3%) of child defecation events. However, caregivers washed hands after cleaning a child's bottom in only 8.1% of the child defecation events where the child's bottom was cleaned (Table 3).

Feces were disposed in the trash in the majority of child defecation events, followed by disposal in the drain, leaving it on the ground, and disposal in the latrine. Feces were disposed properly (in latrine or trash) in the majority (66.7%) of child defecation events. Our definition of proper disposal was based on the assumption that disposing in the latrine or trash would have prevented further contact with people within the immediate household environment. However, contention exists on whether disposal in the trash should be considered proper disposal, because the fecal matter may be isolated in the household but return to the greater neighborhood environment once it leaves the household, perhaps through improper disposal of the trash. Therefore, classification of proper feces disposal could depend on how trash is ultimately disposed. Of the households where child feces were observed to be placed in the trash, 78.9% reported that they primarily disposed of their trash through either a private collection service or private local collection, 15.8% reported disposing trash in an open site, drain, or sea, and 5.3% reported dumping it, which was defined as placing trash in city-provided containers that are collected by the city when full. Although the majority of trash was disposed through formal trash collection processes (private collection, private local collection, or dumping), 15.8% were still disposed in a way that could contaminate the larger neighborhood environment. If we assume that disposal in

the trash is as improper as disposal in a drain or leaving feces on the ground, then child feces were disposed improperly in an alarmingly high percentage (96.7%) of all child defecation events observed. No clear trend existed in child disposal method among wealth quintiles.

Eating was the most commonly observed child behavior. However, children were observed to use utensils (instead of hands) to eat in only 14.9% of the eating events. Enumerators only observed one time (0.3% of all child eating events) when a child washed hands before eating. The event was observed in a girl 1-2 years old, and soap was not used during that event. We did not observe any instances of child handwashing with soap before eating.

Purchased food was the food source for the majority of eating events observed for all age groups and both genders. No child <1 year of age was observed to eat raw produce, and children 1-2 years old and >2 years old were both observed to eat raw produce about 5% of the time.

### *Child locations*

Children were observed to be off the ground, on improved ground, and on unimproved ground each for about a quarter of the time (Figure 1). They were out of view for a fifth of the time. In other words, for all the time where the enumerator could see the child, children were observed to be off the ground, on improved ground, and on unimproved ground for about a third of the time each (33.6%, 34.4%, and 31.5% of the total time observed, respectively). They were rarely observed to be in a stagnant water trash area or in drains.

### *Caregiver and child behaviors by demographic characteristics*

Boys washed hands or bathed more often than girls (Table 5). Children washed hands or bathed more often in households that ran a business out of the house compared to households that didn't. No clear trend existed between frequency of child handwashing or bathing events and wealth quintile.

Child hygiene events (handwashing or bathing after defecation and handwashing before eating) occurred in only 2.0% of all child hygiene opportunities (before eating and after defecation). Hygiene opportunity fulfillment did not differ greatly between demographic groups.

Caregivers fulfilled only 8.1% of handwashing opportunities. They tended to fulfill handwashing opportunities more often in households with businesses than households without businesses. Caregivers fulfilled opportunities most in Alajo neighborhood, followed by Bukom, Old Fadama, and Shiabu. No clear trend existed between the percent of handwashing opportunities fulfilled and wealth quintile.

### *E. coli and enterococci child hand contamination*

We collected a total of 49 child handrinses. Children's hands were contaminated with a median of 190.00 *E. coli* CFU per two hands (range 2.25 – 31,500.00 CFU per two hands) (Figure 2). For enterococci, children's hands were contaminated with a median of 2,700.00 enterococci CFU per two hands (range 22.52 – 84,000.00 CFU per two hands) (Figure 3).

### *Child hand contamination, hygiene behaviors, and household conditions*

A total of 40 children were included in the bivariate and multivariate analyses, based on having hand contamination data, child behavioral data, caregiver behavioral data, and household conditions data. In our bivariate analysis, we saw a weak association between the frequency of child bathing events and enterococci child hand contamination ($\beta$= -0.256, 95% CI=-0.516, 0.004) (Table 6). Because the interaction between child location cleanliness and child mobility level was not significant in either the *E. coli* model or the enterococci model (both $p>0.05$), the interaction term was dropped from both multivariate models. Multivariate analysis did not reveal any hygiene behaviors or household conditions that were associated with *E. coli* or enterococci child hand contamination (Table 7).

## Discussion

This study was one of the first to conduct structured observation on behaviors of children and caregivers in the low-income peri-urban household setting, with an emphasis on quantifying these behaviors to understand risk of exposure to fecal pathogens in children under five years of age. We observed numerous opportunities for fecal hand contamination, through caregiver and child behaviors and child locations. Contamination opportunities were rarely intercepted by hygiene behaviors, signaling frequent contamination risks in the household environment.

We observed a high number of handwashing and hygiene opportunities for both children and their caregivers. These opportunities were fulfilled slightly more frequently among caregivers than among children but were rare for both. When handwashing did occur, caregivers used soap a third of the time. Soap was used in only a tenth of child handwashing events but in the majority of child bathing events. We observed a total of 46

caregiver handwashing events, and 44 handwashing events fulfilled handwashing opportunities. Therefore, the low percentage of handwashing opportunity fulfillment did not seem to be due to handwashing at ineffectual times (i.e. not during a handwashing opportunity like after latrine-use or sullage disposal) so much as not enough handwashing. Low handwashing rates might have been due to the fact that none of the households in this study had a handwashing station (Biran *et al.*, 2005, Luby *et al.*, 2009). Since no households in the study had a handwashing station, we could not assess the relationship between presence of a handwashing facility and handwashing behaviors or child hand contamination.

Data on child behaviors revealed frequent contact with other children and adults. As children increased in age, their contact with other children increased, likely because of increased mobility and play. Although a clear trend did not exist between age groups in the percent of child defecation events followed by handwashing or bathing, the smallest percent of defecation events followed by handwashing or bathing occurred among the one to two year old age group. Contact with other children and adults was also more frequent for boys than girls. Therefore, person-to-person contact may be a frequent route of contamination transmission within the household, particularly for boys one to two years old.

We observed many opportunities for fecal contamination around child defecation events. Although the majority of children's bottoms were cleaned after a defecation event, few (8.1%) of these child-cleaning events were followed by caregiver handwashing. Even if the child cleaned him- or herself, only 17.1% of child defecation events were followed by child handwashing or bathing, and even fewer were followed by handwashing or bathing with soap.

Child feces disposal in latrines was rarely observed, perhaps because so few households (9.6%) had a latrine on the compound. If we assume that disposing child feces in

the trash successfully isolates fecal matter from the immediate household environment, then the majority of child defecation events observed were disposed in a way that properly removed feces from the household. However, disposal of child feces in the trash does not mitigate overall exposure, as this waste may not be hygienically disposed and contamination may occur outside the household, in the greater neighborhood environment. Improperly disposed child feces may accumulate in drains or in neighborhood SWATA, resulting in drains with contamination levels similar to that of raw sewage (SaniPath, *unpublished data*). Although children under five years of age were in drains and SWATA for less than 1% of the total observation time, child hand contamination from drains and SWATA are highly risky events, even if they are rare. Moreover, contamination from drains and SWATA could spread to larger swaths of dirt in the neighborhood through rain and flooding, and children under five years of age may come into contact with fecal matter through the dirt. Although children were on improved ground about 27% of the time, they were still on unimproved ground (dirt) for a quarter of the time.

Despite the high proportion of unfulfilled caregiver and child hygiene opportunities, the suboptimal disposal of child feces, and large amount of time children spent in potentially contaminated locations, we did not find evidence of association between these factors and child hand contamination. The frequency of child bathing events was the factor most strongly related to enterococci child hand contamination in the bivariate analysis and with *E. coli* and enterococci child hand contamination in the multivariate analysis. As expected, we observed an inverse relationship: the greater the frequency of child bathing events, the less the child hand contamination.

### *Strengths and limitations*

Time and resources limited our sample size. Although a total of 117 households participated in our study, we could only include 40 households in our assessment of the observations on child hand contamination. This decrease in sample size potentially affected our power to detect significant associations.

Children were out of enumerators' view for about a fifth of the total observation time. Key child behaviors of interest could not be recorded during those times. Therefore, certain behaviors like being in drains or defecating outside the household may have been under-observed. Since the majority of households reported that adults typically use public latrines to defecate, caregiver defecation events could also have been under-observed for this same reason.

Although we observed some households twice, ideally we would have observed each household multiple times in order to address the lack of repeatability of hygiene behavioral observations (Cousens *et al.*, 1996). However, time and resources prohibited repeated observations.

Despite these limitations, our study contributed rich observational data on the behaviors of children under five years of age and their caregivers, specifically for the low-income peri-urban setting. A particular strength was our study design, which included collecting both observational and microbiological data, both of which can produce more objective and reliable data than self-reported methods (Curtis *et al.*, 1993; Pickering *et al.*, 2010). We were able to link observed behaviors to microbiological data to quantify the effect of child and caregiver behaviors on child hand contamination. Inclusion of household survey data enriched our analysis by allowing us to examine and control for household conditions in our exploration of behaviors and exposure.

**Conclusion**

Our findings revealed that a high number of opportunities for fecal hand contamination exist in the normal, day-to-day behaviors of children under five years of age and their caregivers in the household. In a contaminated, urban environment such as Accra, this may lead to high rates of enteric diseases and related outcomes including undernutrition and stunting (Humphrey, 2009). Hygiene behaviors such as handwashing and bathing with soap occurred at low levels, particularly among children. Household conditions such as the dearth of sanitation facilities and non-existence of handwashing stations could have contributed to the low frequency of hygiene behaviors and of proper child feces disposal observed. Child feces were extremely rarely disposed in latrines, leaving open many possible transmission pathways for the child fecal matter to enter the household and larger neighborhood environment.

Increasing the frequency of child bathing events could help to decrease child hand contamination. Future studies with larger sample sizes could help confirm the effect of child bathing on hand contamination, illuminate why child bathing might be effective at decreasing contamination, and explore the plausibility of encouraging more frequent child bathing as a positive hygiene behavior for children under five years of age in the peri-urban household context. Reasons behind the low rates of handwashing with soap among Ghanaian caregivers remain unclear (Scott *et al.*, 2007). In order to increase this hygiene behavior whose effectiveness against hand contamination has already been well established, additional qualitative studies are needed to better understand ways to encourage handwashing with soap, not only among caregivers but also among children under five years of age. Finally, the lack of sanitation and hygiene infrastructure is of great concern, because not only does it prevent the proper separation of fecal material from the household and

neighborhood environments but it also could make it more difficult for children and caregivers to practice proper hygiene behaviors. Although the presence of WASH facilities may not necessarily result in their use (Clasen *et al.*, 2014; Kwiringira *et al.*, 2014), the serious underdevelopment of infrastructure could be a major barrier to improving hygiene behaviors and decreasing exposures to fecal contamination in urban and peri-urban households.

# Tables and figures

**Table 1. Demographics***

| Variable | Total survey (overall n=117) N | n (%) or median (range) | Alajo (overall n=30) N | n (%) or median (range) | Bukom (overall n=25) N | n (%) or median (range) |
|---|---|---|---|---|---|---|
| Respondent status | | | | | | |
| Female non-head of household | 113 | 75 66.4% | 28 | 18 64.3% | 24 | 16 66.7% |
| Female head of household | 113 | 31 27.4% | 28 | 8 28.6% | 24 | 7 29.2% |
| Male head of household | 113 | 7 6.2% | 28 | 2 7.1% | 24 | 1 4.2% |
| No. of people in household | 106 | 4.5 (2.0 - 41.0) | 29 | 4.0 (2.0 - 41.0) | 21 | 5.0 (3.0-14.0) |
| No. of people in compound | 28 | 19.5 (2.0 - 64.0) | 10 | 20.0 (5.0 - 52.0) | 4 | 21.5 (9.0 - 54.0) |
| No. of children <5 years in household | 110 | 1.0 (1.0 - 6.0) | 28 | 1.0 (1.0 - 3.0) | 23 | 1.0 (1.0 - 5.0) |
| % renter | 113 | 46 40.7% | 29 | 17 58.6% | 24 | 4 16.7% |
| % electricty | 114 | 102 89.5% | 29 | 27 93.1% | 24 | 18 75.0% |
| % business | 107 | 61 57.0% | 30 | 18 60.0% | 21 | 12 57.1% |
| % business vends prepared food | 62 | 31 50.0% | 18 | 10 55.6% | 12 | 5 41.7% |
| Religion | | | | | | |
| Christian | 110 | 75 68.2% | 30 | 25 83.3% | 23 | 21 91.3% |
| Muslim | 110 | 34 30.9% | 30 | 5 16.7% | 23 | 1 4.3% |
| No religion | 110 | 1 0.9% | 30 | 0 0.0% | 23 | 1 4.3% |
| Level of education of respondent | | | | | | |
| No formal education | 107 | 38 35.5% | 30 | 4 13.3% | 22 | 5 22.7% |
| Some or completed primary school | 107 | 55 51.4% | 30 | 20 66.7% | 22 | 14 63.6% |
| Completed at least secondary school | 107 | 14 13.1% | 30 | 6 20.0% | 22 | 3 13.6% |
| Primary source of drinking water | | | | | | |
| Sachets | 110 | 77 70.0% | 29 | 19 65.5% | 21 | 14 66.7% |
| Tap from pipe | 110 | 31 28.2% | 29 | 10 34.5% | 21 | 6 28.6% |
| Tap from tank | 110 | 2 1.8% | 29 | 0 0.0% | 21 | 1 4.8% |
| Sources of water for cooking and hygiene | | | | | | |
| Sachet/water bottle | 114 | 1 0.9% | 29 | 1 3.4% | 24 | 0 0.0% |
| Sachet/water bottle & tap from pipe network | 114 | 2 1.8% | 29 | 0 0.0% | 24 | 1 4.2% |
| Tap from pipe network | 114 | 99 86.8% | 29 | 28 96.6% | 24 | 21 87.5% |
| Tap from pipe network & tap from polytank | 114 | 1 0.9% | 29 | 0 0.0% | 24 | 0 0.0% |
| Tap from polytank | 114 | 11 9.6% | 29 | 0 0.0% | 24 | 2 8.3% |
| % with latrine(s) on compound | 115 | 11 9.6% | 30 | 8 26.7% | 24 | 1 4.2% |
| % with a private household latrine | 112 | 0 0.0% | 27 | 0 0.0% | 24 | 0 0.0% |
| Number of households sharing latrine** | 7 | 7.7 (2.0 - 16.0) | 6 | 8.7 (4.0 - 16.0) | 0 | no data |
| % with handwashing station | | 0 0.0% | | 0 0.0% | | 0 0.0% |
| Money spent on public latrine (C$ cedis) | 97 | 0.4 (0.0 - 3.0) | 23 | 0.3 (0.0 - 3.0) | 21 | 0.6 (0.2 - 3.0) |
| Money spent on drinking water (C$ cedis) | 102 | 0.6 (0.0 - 5.0) | 27 | 0.5 (0.0 - 3.0) | 23 | 0.4 (0.05 - 3.0) |
| Wealth quintile | | | | | | |
| Q1 (lowest/poorest) | 117 | 23 19.7% | 30 | 3 10.0% | 25 | 6 24.0% |
| Q2 | 117 | 24 20.5% | 30 | 3 10.0% | 25 | 4 16.0% |
| Q3 | 117 | 25 21.4% | 30 | 7 23.3% | 25 | 6 24.0% |
| Q4 | 117 | 34 29.1% | 30 | 12 40.0% | 25 | 7 28.0% |
| Q5 (highest/richest) | 117 | 11 9.4% | 30 | 5 16.7% | 25 | 2 8.0% |

*Data are median (range) or n (%); percentages may not sum to 100% due to rounding; N=number of responses without missing data

**Among those who have latrine(s) on compound

**Table 1. Demographics* (continued)**

| Variable | Total survey N | Total survey n (%) | Old Fadama N | Old Fadama n (%) | Shiabu N | Shiabu n (%) |
|---|---|---|---|---|---|---|
| Respondent status | | | | | | |
| Female non-head of household | 113 | 75 66.4% | 31 | 23 74.2% | 30 | 18 60.0% |
| Female head of household | 113 | 31 27.4% | 31 | 6 19.4% | 30 | 10 33.3% |
| Male head of household | 113 | 7 6.2% | 31 | 2 6.5% | 30 | 2 6.7% |
| No. of people in household | 106 | 4.5 (2.0 - 41.0) | 27 | 4.0 (2.0 - 23.0) | 29 | 5.0 (2.0 - 9.0) |
| No. of people in compound | 28 | 19.5 (2.0 - 64.0) | 5 | 17.0 (2.0 - 20.0) | 9 | 35.0 (11.0 - 64.0) |
| No. of children <5 years in household | 110 | 1.0 (1.0 - 6.0) | 30 | 1.0 (1.0 - 6.0) | 29 | 1.0 (1.0 - 3.0) |
| % renter | 113 | 46 40.7% | 31 | 9 29.0% | 29 | 16 55.2% |
| % electricty | 114 | 102 89.5% | 31 | 30 96.8% | 30 | 27 90.0% |
| % business | 107 | 61 57.0% | 31 | 18 58.1% | 25 | 13 52.0% |
| % business vends prepared food | 62 | 31 50.0% | 19 | 12 63.2% | 13 | 4 30.8% |
| Religion | | | | | | |
| Christian | 110 | 75 68.2% | 29 | 2 6.9% | 28 | 27 96.4% |
| Muslim | 110 | 34 30.9% | 29 | 27 93.1% | 28 | 1 3.6% |
| No religion | 110 | 1 0.9% | 29 | 0 0.0% | 28 | 0 0.0% |
| Level of education of respondent | | | | | | |
| No formal education | 107 | 38 35.5% | 29 | 22 75.9% | 26 | 7 26.9% |
| Some or completed primary school | 107 | 55 51.4% | 29 | 6 20.7% | 26 | 15 57.7% |
| Completed at least secondary school | 107 | 14 13.1% | 29 | 1 3.4% | 26 | 4 15.4% |
| Primary source of drinking water | | | | | | |
| Sachets | 110 | 77 70.0% | 31 | 25 80.6% | 29 | 19 65.5% |
| Tap from pipe | 110 | 31 28.2% | 31 | 6 19.4% | 29 | 9 31.0% |
| Tap from tank | 110 | 2 1.8% | 31 | 0 0.0% | 29 | 1 3.4% |
| Sources of water for cooking and hygiene | | | | | | |
| Sachet/water bottle | 114 | 1 0.9% | 31 | 0 0.0% | 30 | 0 0.0% |
| Sachet/water bottle & tap from pipe network | 114 | 2 1.8% | 31 | 0 0.0% | 30 | 1 3.3% |
| Tap from pipe network | 114 | 99 86.8% | 31 | 28 90.3% | 30 | 22 73.3% |
| Tap from pipe network & tap from polytank | 114 | 1 0.9% | 31 | 0 0.0% | 30 | 1 3.3% |
| Tap from polytank | 114 | 11 9.6% | 31 | 3 9.7% | 30 | 6 20.0% |
| % with latrine(s) on compound | 115 | 11 9.6% | 31 | 0 0.0% | 30 | 2 6.7% |
| % with a private household latrine | 112 | 0 0.0% | 32 | 0 0.0% | 29 | 0 0.0% |
| Number of households sharing latrine** | 7 | 7.7 (2.0 - 16.0) | 0 | no data | 1 | 2.0 (2.0-2.0) |
| % with handwashing station | | 0 0.0% | | 0 0.0% | | 0 0.0% |
| Money spent on public latrine (C$ cedis) | 97 | 0.4 (0.0 - 3.0) | 29 | 0.4 (0.1 - 1.6) | 24 | 0.3 (0.0 - 1.5) |
| Money spent on drinking water (C$ cedis) | 102 | 0.6 (0.0 - 5.0) | 28 | 0.5 (0.0 - 1.8) | 24 | 1.0 (0.1 - 5.0) |
| Wealth quintile | | | | | | |
| Q1 (lowest/poorest) | 117 | 23 19.7% | 32 | 9 28.1% | 30 | 5 16.7% |
| Q2 | 117 | 24 20.5% | 32 | 9 28.1% | 30 | 8 26.7% |
| Q3 | 117 | 25 21.4% | 32 | 10 31.3% | 30 | 2 6.7% |
| Q4 | 117 | 34 29.1% | 32 | 3 9.4% | 30 | 12 40.0% |
| Q5 (highest/richest) | 117 | 11 9.4% | 32 | 1 3.1% | 30 | 3 10.0% |

*Data are median (range) or n (%); percentages may not sum to 100% due to rounding; N=number of responses without missing data

**Among those who have latrine(s) on compound

**Table 2: Reported defecation behaviors**

| Defecation location | N* | n | % |
|---|---|---|---|
| Females >12 years | | | |
| Compound latrine | 100 | 19 | 19.0% |
| Public latrine | 100 | 80 | 80.0% |
| Bag/flying toilet | 100 | 1 | 1.0% |
| Males >12 years | | | |
| Compound latrine | 85 | 13 | 15.3% |
| Public latrine | 85 | 69 | 81.2% |
| Bag/flying toilet | 85 | 2 | 2.4% |
| Other | 85 | 1 | 1.2% |
| Children 5-12 years | | | |
| Compound latrine | 78 | 8 | 10.3% |
| Public latrine | 78 | 43 | 55.1% |
| Bag/flying toilet | 78 | 12 | 15.4% |
| Chamber pot | 78 | 9 | 11.5% |
| Outside | 78 | 3 | 3.8% |
| Other | 78 | 3 | 3.8% |

*N=number of responses without missing data

**Table 3: Caregiver behaviors - frequency and details***

| **overall n = 108 unique caregivers** | **N** | **median (range) or n(%)** | **mean (SD)** |
|---|---|---|---|
| Handwashing events | 46 | 0.00 (0.00 - 13.58) | 0.97 (2.15) |
| % with soap | 45 | 15 33.3% | |
| Preparing or handling food | 143 | 2.40 (0.00 - 33.33) | 3.45 (4.00) |
| % following HW | 143 | 13 9.1% | |
| % followed by HW | 143 | 11 7.7% | |
| Sullage disposal | 49 | 0.00 (0.00 - 8.22) | 1.09 (1.82) |
| % followed by HW | 49 | 6 12.2% | |
| Latrine use | 2 | 0.00 (0.00 - 2.34) | 0.04 (0.30) |
| % followed by HW | 2 | 2 100.0% | |
| Handling money | 121 | 2.13 (0.00 - 11.61) | 2.80 (2.71) |
| % followed by HW | 121 | 5 4.1% | |
| Sweeping | 51 | 0.00 (0.00 - 8.11) | 1.10 (1.74) |
| % followed by HW | 51 | 4 7.8% | |
| Cleaning child's bottom | 37 | 0.00 (0.00 - 33.33) | 1.04 (3.41) |
| % followed by HW | 37 | 3 8.1% | |

*Behavior event frequency is reported in median (range) and mean (SD) number of events per 10 person-hours observed per caregiver; N=number of events without missing data

**Table 4a. Child behaviors, overall and by age group***

| | Total (overall n=117 children) | | | <1 year of age (overall n=32 children) | | | 1-2 years of age (overall n=54 children) | | | >2 years of age (overall n=31 children) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | median (range) or n(%) | mean (SD) | N | median (range) or n(%) | mean (SD) | N | median (range) or n(%) | mean (SD) | N | median (range) or n(%) | mean (SD) |
| Median hours of observation | | 4.67 (1.37 - 5.50) | | | 4.83 (1.50 - 5.50) | | | 4.67 (1.37 - 5.35) | | | 4.58 (1.95 - 5.25) | |
| Tallies of behaviors | | | | | | | | | | | | |
| Contact with other children | | 3.20 (0.00 - 16.84) | 3.75 (2.95) | | 2.27 (0.00 - 9.00) | 2.52 (2.34) | | 3.59 (0.00 - 10.48) | 3.67 (2.40) | | 3.78 (0.59 - 16.84) | 5.15 (3.76) |
| Contact with adult | | 2.72 (0.00 - 11.94) | 3.09 (2.34) | | 2.40 (0.00 - 9.79) | 3.17 (2.48) | | 2.81 (0.00 - 11.94) | 3.29 (2.52) | | 2.53 (0.00 - 7.15) | 2.68 (1.86) |
| Fingers in mouth | | 2.24 (0.00 - 19.00) | 3.27 (3.34) | | 3.58 (0.00 - 19.00) | 4.94 (4.79) | | 1.90 (0.00 - 12.22) | 2.79 (2.59) | | 2.12 (0.00 - 6.91) | 2.39 (1.83) |
| Objects in mouth | | 1.12 (0.00 - 14.80) | 1.83 (2.34) | | 1.79 (0.00 - 12.20) | 2.63 (2.82) | | 1.00 (0.00 - 14.80) | 1.70 (2.31) | | 0.72 (0.00 - 5.60) | 1.23 (1.55) |
| Handwashing events | 10 | 0.00 (0.00 - 6.52) | 0.20 (0.87) | 0 | 0.00 (0.00 - 0.00) | 0.00 (0.00) | 5 | 0.00 (0.00 - 6.52) | 0.22 (1.02) | 5 | 0.00 (0.00 - 4.44) | 0.36 (1.01) |
| % with soap | 10 | 1 10% | | 0 | 0.00 0.0% | | 5 | 1 20.0% | | 5 | 0 0.0% | |
| Bathing events | 58 | 0.00 (0.00 - 4.94) | 1.06 (1.20) | 16 | 0.00 (0.00 - 4.00) | 1.04 (1.18) | 26 | 0.00 (0.00 - 4.26) | 1.05 (1.20) | 16 | 0.00 (0.00 - 4.94) | 1.09 (1.26) |
| % with soap | 58 | 43 75.4% | | 16 | 13 81.3% | | 25 | 18 72.0% | | 16 | 12 75.0% | |
| Defecation events | 41 | 0.00 (0.00 - 4.53) | 0.73 (1.15) | 11 | 0.00 (0.00 - 4.00) | 0.70 (1.10) | 16 | 0.00 (0.00 - 4.53) | 0.61 (1.12) | 14 | 0.00 (0.00 - 4.35) | 0.98 (1.24) |
| % followed by handwashing/bathing | 41 | 7 17.1% | | 11 | 2 18.2% | | 16 | 2 12.5% | | 14 | 3 21.4% | |
| % followed by handwashing/bathing with soap | 41 | 4 9.8% | | 11 | 2 18.2% | | 16 | 1 6.3% | | 14 | 1 7.1% | |
| % child is cleaned | 39 | 36 92.3% | | 10 | 9 90.0% | | 16 | 14 87.5% | | 14 | 13 92.9% | |
| % feces are disposed in latrine | 30 | 1 3.3% | | 7 | 0 0.0% | | 12 | 1 8.3% | | 11 | 0 0.0% | |
| % feces are put in trash | 30 | 19 63.3% | | 7 | 4 57.1% | | 12 | 9 75.0% | | 11 | 6 54.5% | |
| % feces are put in drain | 30 | 7 23.3% | | 7 | 2 28.6% | | 12 | 2 16.7% | | 11 | 3 27.3% | |
| % feces are left on ground | 30 | 3 10.0% | | 7 | 1 14.3% | | 12 | 0 0.0% | | 11 | 2 18.2% | |
| % feces disposed properly (latrine, trash) | 30 | 20 66.7% | | 7 | 4 57.1% | | 12 | 10 83.3% | | 11 | 6 54.5% | |
| % feces disposed improperly (drain, ground) | 30 | 10 33.3% | | 7 | 3 42.9% | | 12 | 2 16.7% | | 11 | 5 45.5% | |
| Eating events | 369 | 0.00 (0.00 - 22.00) | 6.95 (4.13) | 105 | 7.15 (0.00 - 16.07) | 7.05 (4.24) | 176 | 6.64 (0.00 - 22.00) | 7.18 (4.37) | 88 | 5.71 (0.00 - 16.17) | 6.43 (3.64) |
| % using utensiles | 221 | 33 14.9% | | 38 | 9 23.7% | | 100 | 14 14.0% | | 83 | 10 12.0% | |
| % following handwashing | 369 | 1 0.3% | | 105 | 0 0.0% | | 176 | 1 0.6% | | 88 | 0 0.0% | |
| % following handwashing with soap | 369 | 0 0.0% | | 105 | 0 0.0% | | 176 | 0 0.0% | | 88 | 0 0.0% | |
| % food prepared at home | 221 | 60 27.1% | | 35 | 11 31.4% | | 105 | 36 34.3% | | 81 | 13 16.0% | |
| % food purchased | 221 | 132 59.7% | | 35 | 22 62.9% | | 105 | 53 50.5% | | 81 | 57 70.4% | |
| % Raw produce | 221 | 9 4.1% | | 35 | 0 0.0% | | 105 | 5 4.8% | | 81 | 4 4.9% | |
| % other/don't know | 221 | 20 9.0% | | 35 | 2 5.7% | | 105 | 11 10.5% | | 81 | 7 8.6% | |

*Tallies are reported in mean (range) and median (SD) events per person-hour observed per child. Other behaviors are reported in n(%) or mean (range) and median (SD) events per 10 person-hours observed per child; N=number of events without missing data

**Table 4b. Child behaviors, overall and by sex***

| | Total (overall n=117 children) | | | Boys (overall n=52 boys) | | | Girls (overall n=64 girls) | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | median (range) or n(%) | mean (SD) | N | median (range) or n(%) | mean (SD) | N | median (range) or n(%) | mean (SD) |
| Median hours of observation | | 4.67 (1.37 - 5.50) | | | 4.71 (2.15 - 5.33) | | | 4.56 (1.37 - 5.50) | |
| Tallies of behaviors | | | | | | | | | |
| Contact with other children | | 3.20 (0.00 - 16.84) | 3.75 (2.95) | | 3.85 (0.00 - 16.84) | 4.25 (3.42) | | 2.86 (0.00 - 10.47) | 3.34 (2.49) |
| Contact with adult | | 2.72 (0.00 - 11.94) | 3.09 (2.34) | | 2.97 (0.00 - 9.79) | 3.26 (2.48) | | 2.64 (0.00 - 11.94) | 2.99 (2.25) |
| Fingers in mouth | | 2.24 (0.00 - 19.00) | 3.27 (3.34) | | 1.90 (0.00 - 19.00) | 3.24 (3.81) | | 2.64 (0.00 - 12.80) | 3.33 (2.95) |
| Objects in mouth | | 1.12 (0.00 - 14.80) | 1.83 (2.34) | | 1.06 (0.00 - 5.60) | 1.68 (1.68) | | 1.15 (0.00 - 14.80) | 1.96 (2.78) |
| Handwashing events | 10 | 0.00 (0.00 - 6.52) | 0.20 (0.87) | 6 | 0.00 (0.00 - 6.52) | 0.26 (1.06) | 4 | 0.00 (0.00 - 4.44) | 0.14 (0.69) |
| % with soap | 10 | 1 10% | | 6 | 1 16.7% | | 4 | 0 0.0% | |
| Bathing events | 58 | 0.00 (0.00 - 4.94) | 1.06 (1.20) | 30 | 1.89 (0.00 - 4.26) | 1.24 (1.24) | 28 | 0.00 (0.00 - 4.94) | 0.93 (1.15) |
| % with soap | 58 | 43 75.4% | | 29 | 21 72.4% | | 28 | 22 78.6% | |
| Defecation events | 41 | 0.00 (0.00 - 4.53) | 0.73 (1.15) | 20 | 0.00 (0.00 - 4.53) | 0.79 (1.25) | 19 | 0.00 (0.00 - 2.58) | 0.63 (0.99) |
| % followed by handwashing/bathing | 41 | 7 17.1% | | 20 | 2 10.0% | | 19 | 5 26.3% | |
| % followed by handwashing/bathing with soap | 41 | 4 9.8% | | 20 | 1 5.0% | | 19 | 3 15.8% | |
| % child is cleaned | 39 | 36 92.3% | | 20 | 17 85.0% | | 17 | 17 100.0% | |
| % feces are disposed in latrine | 30 | 1 3.3% | | 15 | 0 0.0% | | 15 | 1 6.7% | |
| % feces are put in trash | 30 | 19 63.3% | | 15 | 8 53.3% | | 15 | 11 73.3% | |
| % feces are put in drain | 30 | 7 23.3% | | 15 | 5 33.3% | | 15 | 2 13.3% | |
| % feces are left on ground | 30 | 3 10.0% | | 15 | 2 13.3% | | 15 | 1 6.7% | |
| % feces disposed properly (latrine, trash) | 30 | 20 66.7% | | 15 | 8 53.3% | | 15 | 12 80.0% | |
| % feces disposed improperly (drain, ground) | 30 | 10 33.3% | | 15 | 7 46.7% | | 15 | 3 20.0% | |
| Eating events | 369 | 0.00 (0.00 - 22.00) | 6.95 (4.13) | 168 | 7.15 (0.00 - 16.15) | 7.12 (4.11) | 195 | 5.90 (0.00 - 22.00) | 6.73 (4.15) |
| % using utensils | 221 | 33 14.9% | | 102 | 15 14.7% | | 117 | 18 15.4% | |
| % following handwashing | 369 | 1 0.3% | | 168 | 0 0.0% | | 195 | 1 0.5% | |
| % following handwashing with soap | 369 | 0 0.0% | | 168 | 0 0.0% | | 195 | 0 0.0% | |
| % food prepared at home | 221 | 60 27.1% | | 99 | 23 23.2% | | 118 | 36 30.5% | |
| % food purchased | 221 | 132 59.7% | | 99 | 66 66.7% | | 118 | 63 53.4% | |
| % raw produce | 221 | 9 4.1% | | 99 | 5 5.1% | | 118 | 4 3.4% | |
| % other/don't know | 221 | 20 9.0% | | 99 | 5 5.1% | | 118 | 15 12.7% | |

*Tallies are reported in mean (range) and median (SD) events per person-hour observed per child. Other behaviors are reported in n(%) or mean (range) and median (SD) events per 10 person-hours observed per child; N=number of events without missing data

**Table 5: Frequency and proportions of key hygiene behaviors, by demographic characteristics***

| | Frequency of child handwashing or bathing events (events per 10 p-hrs) | | | % Child hygiene opportunities fulfilled** | | | % Caregiver handwashing opportunities fulfilled*** | | |
|---|---|---|---|---|---|---|---|---|---|
| | median (range) | | mean (SD) | N | n | % | N | n | % |
| Overall | 1.84 | (0.00 - 8.70) | 1.26 (1.42) | 410 | 8 | 2.0% | 546 | 44 | 8.1% |
| Child sex | | | | | | | | | |
| Boys | 2.00 | (0.00 - 8.70) | 1.51 (1.60) | 188 | 2 | 1.1% | N/A | | |
| Girls | 0.00 | (0.00 - 4.94) | 1.07 (1.24) | 214 | 6 | 2.8% | N/A | | |
| Household business presence | | | | | | | | | |
| Business | 1.83 | (0.00 - 8.70) | 1.28 (1.57) | 216 | 3 | 1.4% | 309 | 30 | 9.7% |
| Non-business | 0.89 | (0.00 - 4.26) | 1.18 (1.26) | 147 | 3 | 2.0% | 191 | 12 | 6.3% |
| Neighborhood | | | | | | | | | |
| Alajo | 0.00 | (0.00 - 8.70) | 1.17 (1.96) | 100 | 2 | 2.0% | 150 | 14 | 9.3% |
| Bukom | 1.92 | (0.00 - 2.26) | 1.26 (1.03) | 95 | 1 | 1.1% | 96 | 8 | 8.3% |
| Old Fadama | 1.79 | (0.00 - 2.59) | 1.07 (1.06) | 102 | 2 | 2.0% | 127 | 9 | 7.1% |
| Shiabu | 2.00 | (0.00 - 4.94) | 1.54 (1.39) | 113 | 3 | 2.7% | 147 | 10 | 6.8% |
| Child age | | | | | | | | | |
| <1 year | 0.00 | (0.00 - 4.00) | 1.04 (1.18) | 116 | 2 | 1.7% | N/A | | |
| 1-2 years | 0.93 | (0.00 - 8.70) | 1.27 (1.59) | 192 | 3 | 1.6% | N/A | | |
| >2 yrs | 1.98 | (0.00 - 4.94) | 1.45 (1.34) | 102 | 3 | 2.9% | N/A | | |
| Asset score wealth quintile | | | | | | | | | |
| Q1 (lowest/poorest) | 1.98 | (0.00 - 3.41) | 1.24 (1.15) | 79 | 2 | 2.5% | 107 | 4 | 3.7% |
| Q2 | 1.79 | (0.00 - 2.35) | 1.04 (1.03) | 84 | 0 | 0.0% | 116 | 7 | 6.0% |
| Q3 | 0.94 | (0.00 - 8.70) | 1.38 (1.93) | 82 | 2 | 2.4% | 116 | 19 | 16.4% |
| Q4 | 2.00 | (0.00 - 4.94) | 1.40 (1.52) | 120 | 4 | 3.3% | 170 | 11 | 6.5% |
| Q5 (highest/richest) | 0.00 | (0.00 - 2.87) | 1.05 (1.23) | 45 | 0 | 0.0% | 37 | 3 | 8.1% |

*Data reported in n(%) or median (range) and mean (SD) number of events per person-hour observed; n is number of opportunities fulfilled or number of defecation events where child feces are properly disposed; N=number of opportunities without missing data

**Child hygiene opportunities include defecation and eating events. Opportunity fulfilled if defecation event was followed by handwashing or bathing and eating event was preceded by handwashing

***Caregiver handwashing opportunities include before preparing food, after preparing food, after cleaning child's bottom, after sullage disposal, after using latrine, after handling money, and after sweeping

****Proper disposal defined as in child feces disposed in latrine or trash, not in drain or left on ground

**Table 6. Bivariate SLR models of child hand contamination as a function of hygiene behaviors and household conditions***

| | E. coli | | | Enterococci | | |
|---|---|---|---|---|---|---|
| | Beta est. | 95% CI | p-value | Beta est. | 95% CI | p-value |
| Caregiver behaviors | | | | | | |
| Frequency of caregiver handwashing events | 0.039 | (-0.108, 0.186) | 0.595 | -0.031 | (-0.162, 0.100) | 0.636 |
| Proportion of caregiver handwashing opportunities unfulfilled | -0.024 | (-1.732, 1.683) | 0.977 | 0.123 | (-1.398, 1.643) | 0.871 |
| Child behaviors | | | | | | |
| Frequency of child handwashing events | -0.110 | (-0.468, 0.248) | 0.538 | 0.116 | (-0.202, 0.434) | 0.465 |
| Frequency of child bathing events | -0.068 | (-0.374, 0.238) | 0.656 | -0.256 | (-0.516, 0.004) | 0.053 |
| Proportion of child defecation events not followed by bathing/handwashing | -0.013 | (-0.793, 0.767) | 0.974 | -0.020 | (-0.715, 0.675) | 0.954 |
| Proportion of child defecation events where child bottom not cleaned | -0.239 | (-2.323, 1.846) | 0.818 | -0.593 | (-2.441, 1.255) | 0.520 |
| Proportion of time child spent in unclean location | -0.270 | (-1.442, 0.902) | 0.644 | 0.132 | (-0.914, 1.179) | 0.799 |
| Child mobility level | 0.229 | (-0.914, 1.179) | 0.322 | 0.091 | (-0.325, 0.507) | 0.660 |
| Proportion of child defecation events where feces improperly disposed | 0.154 | (-1.340, 1.648) | 0.836 | -0.674 | (-1.987, 0.640) | 0.306 |
| Frequency of child contact with other children | -0.011 | (-0.127, 0.106) | 0.855 | 0.006 | (-0.098, 0.110) | 0.903 |
| Frequency of child contact with adults | 0.018 | (-0.105, 0.141) | 0.773 | 0.015 | (-0.095, 0.125) | 0.786 |
| HH conditions | | | | | | |
| Absence of sanitation facility | -0.237 | (-1.090, 0.616) | 0.577 | 0.193 | (-0.568, 0.953) | 0.611 |
| Feces visible around compound grounds | -0.075 | (-1.063, 0.913) | 0.879 | 0.355 | (-0.517, 1.228) | 0.415 |
| Business run from compound | 0.143 | (-0.558, 0.845) | 0.681 | -0.010 | (-0.636, 0.617) | 0.976 |
| Demographics | | | | | | |
| Child age | 0.036 | (-0.399, 0.471) | 0.868 | 0.229 | (-0.151, 0.610) | 0.230 |
| Child sex | 0.077 | (-0.605, 0.759) | 0.820 | -0.049 | (-0.657, 0.558) | 0.870 |
| Household wealth quintile | -0.091 | (-0.330, 0.148) | 0.447 | -0.056 | (-0.270, 0.158) | 0.599 |

*Simple linear regression (SLR); child hand contamination as log 10 CFU per two hands

**Table 7. Multivariate MLR model of child hand contamination as a function of hygiene behaviors and household conditions***

| | E. coli | | | Enterococci | | |
|---|---|---|---|---|---|---|
| Variable | Beta est. | 95% CI | p-value | Beta est. | 95% CI | p-value |
| Caregiver behaviors | | | | | | |
| Frequency of caregiver handwashing events | 0.176 | (-0.149, 0.502) | 0.271 | -0.123 | (-0.383, 0.138) | 0.336 |
| Proportion of caregiver handwashing opportunities unfulfilled | -0.413 | (-5.163, 4.337) | 0.858 | -2.086 | (-5.890, 1.717) | 0.265 |
| Child behaviors | | | | | | |
| Frequency of child handwashing events | -0.290 | (-0.989, 0.410) | 0.397 | 0.100 | (-0.460, 0.661) | 0.712 |
| Frequency of child bathing events | -0.390 | (-0.974, 0.194) | 0.178 | -0.346 | (-0.814, 0.122) | 0.138 |
| Proportion of child defecation events not followed by bathing/handwashing | -0.019 | (-1.378, 1.340) | 0.977 | 0.377 | (-0.711, 1.465) | 0.477 |
| Proportion of child defecation events where child bottom not cleaned | 0.057 | (-4.170, 4.284) | 0.978 | 0.243 | (-3.142, 3.628) | 0.882 |
| Proportion of time child spent in unclean location | -1.232 | (-3.511, 1.048) | 0.272 | -0.488 | (-2.314, 1.337) | 0.582 |
| Child mobility level | 0.145 | (-0.789, 1.078) | 0.749 | 0.071 | (-0.676, 0.819) | 0.844 |
| Proportion of child defecation events where feces improperly disposed | -0.025 | (-3.653, 3.603) | 0.989 | -1.324 | (-4.229, 1.581) | 0.352 |
| Frequency of child contact with other children | 0.017 | (-0.214, 0.248) | 0.881 | 0.020 | (-0.165, 0.205) | 0.826 |
| Frequency of child contact with adults | -0.009 | (-0.234, 0.216) | 0.932 | 0.035 | (-0.145, 0.215) | 0.691 |
| HH conditions | | | | | | |
| Absence of sanitation facility | 0.626 | (-1.635, 2.887) | 0.569 | -0.104 | (-1.915, 1.707) | 0.906 |
| Feces visible around compound grounds | -0.353 | (-2.403, 1.697) | 0.723 | -0.317 | (-1.959, 1.325) | 0.691 |
| Business run from compound | 0.215 | (-1.006, 1.435) | 0.717 | 0.005 | (-0.972, 0.982) | 0.992 |

*Multiple linear regression (MLR); child hand contamination as log 10 CFU per two hands; controlling for child age, child sex, household wealth quintile, and neighborhood

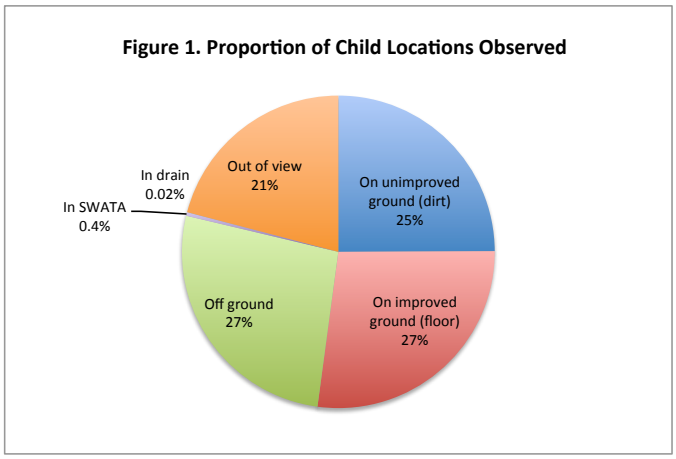



**Figure 1. Proportions of Child Locations**

| Location | % of person-hours observed |
|---|---|
| On unimproved ground (dirt) | 24.9% |
| On improved ground (floor) | 27.2% |
| Off ground | 26.6% |
| In SWATA* | 0.4% |
| In drain | 0.0% |
| Out of view | 20.9% |

*Stagnant water trash area (SWATA)

**Figure 2. Distribution of E. Coli Hand Contamination of Children Under Five Years Old**

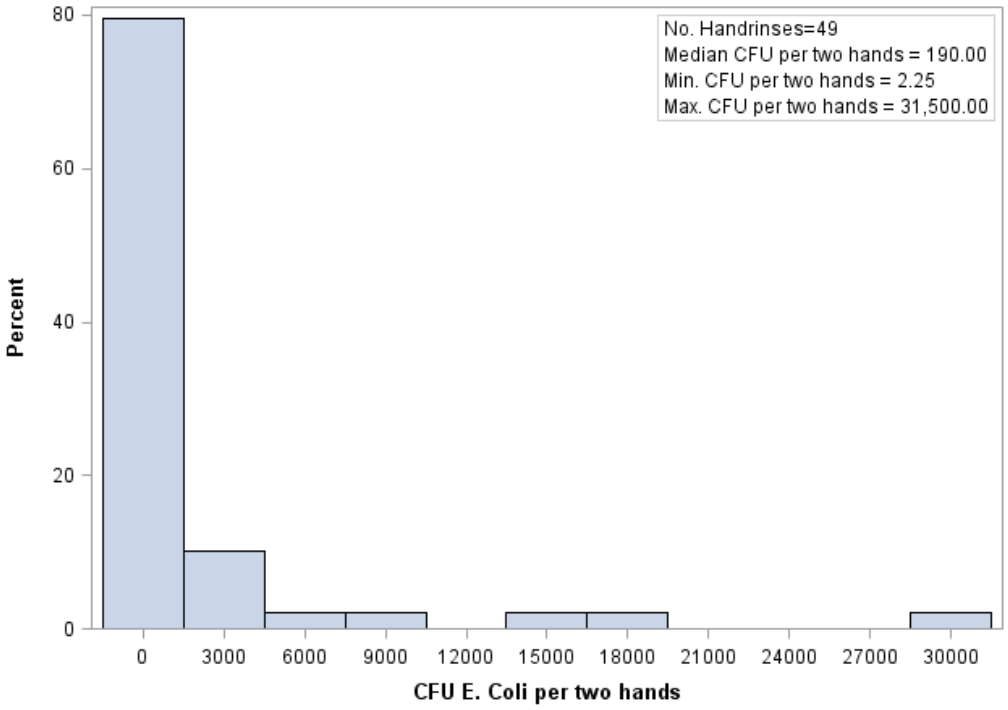
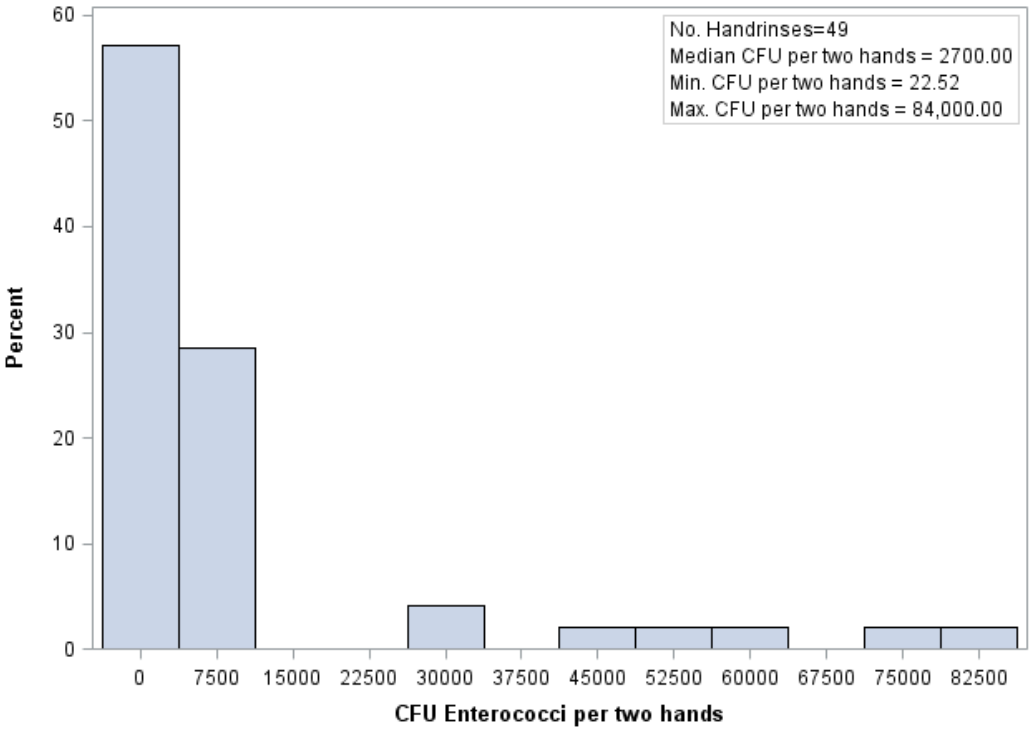


**Figure 3. Distribution of Enterococci Hand Contamination of Children Under Five Years Old**



References

Alam, N, Wojtyniak, B, Henry, F J, et al. (1989). Mothers' personal and domestic hygiene and diarrhoea incidence in young children in rural Bangladesh. International Journal of Epidemiology, 18(1), 242-7.

Aunger, R, Schmidt, W, Ranpura, A, et al. (2010). Three kinds of psychological determinants for hand-washing behaviour in kenya. Social science & medicine, 70(3), 383-91.

Awuah, E, Nyarko, K B, & Owusu, P A. (2009). Water and sanitation in Ghana. Desalination 248(1-3), 460-467.

Bali, D. (2013). Stolen trash bins contribute to malaria, flooding. The pulitzer center. Retrieved from http://pulitzercenter.org/reporting/africa-ghana-stolen-trash-bin-clogged-gutter-malaria-flood-public-health-water-borne-disease-epidemic

Biran, A, Tabyshalieva, A, & Salmorbekova, Z. (2005). Formative research for hygiene promotion in Kyrgyzstan. Health policy and planning, 20(4), 213-21.

Black, R E, Cousens, S, Johnson, H L, et al. (2010). Global, regional, and national causes of child mortality in 2008: A systematic analysis. Lancet (London, England), 375(9730), 1969-87.

Boadi, K O, & Kuitunen, M. (2005). Environment, wealth, inequality and the burden of disease in the accra metropolitan area, ghana. International journal of environmental health research, 15(3), 193-206.

Brown, A S, Raff, S, & Hotez, P. (2009). Soil-transmitted helminths: worms are the most common pathogens of mankind. In C. U. Battle (Ed.), *Essentials of public health biology: a guide for the study of pathophysiology* (pp.287-300). Sudbury, MA: Jones and Bartlett Publishers.

Clasen, T, Boisson, S, Routray, P, et al. (2014). Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in odisha, india: A cluster-randomised trial. The Lancet Global Health, 2(11), e645-53.

Cousens, S, Kanki, B, Toure, S, et al. (1996). Reactivity and repeatability of hygiene behaviour: Structured observations from burkina faso. Social science & medicine, 43(9), 1299-308.

Crompton, D W, & Savioli, L. (1993). Intestinal parasitic infections and urbanization. Bulletin of the World Health Organization, 71(1), 1-7.

Curtis V, Cousens S, Mertens T, Traore E, Kanki B, et al. (1993) Structured observations of hygiene behaviours in Burkina Faso: validity, variability, and utility. Bull World Health Organ 71: 23–32.

Curtis, V, Kanki, B, Cousens, S, et al. (2001). Evidence of behaviour change following a hygiene promotion programme in burkina faso. Bulletin of the World Health Organization, 79(6), 518-27.

Dangour, A D, Watson, L, Cumming, O, et al. (2013). Interventions to improve water quality and supply, sanitation and hygiene practices, and their effects on the nutritional status of children. Cochrane Database of Systematic Reviews, 8, CD009382.

Davis, S M, Worrell, C M, Wiegand, R E, et al. (2014). Soil-transmitted helminths in pre-school-aged and school-aged children in an urban slum: A cross-sectional study of prevalence, distribution, and associated exposures. The American journal of tropical medicine and hygiene, 91(5), 1002-10.

Eisenberg, J N, Trostle, J, Sorensen, R J, et al. (2012). Toward a systems approach to enteric pathogen transmission: From individual independence to community interdependence. Annual review of public health, 33, 239-57.

Freeman, M C, Stocks, M E, Cumming, O, et al. (2014). Hygiene and health: Systematic review of handwashing practices worldwide and update of health effects. TM & IH. Tropical medicine and international health, 19(8), 906-16. doi: 10.1111/tmi.12339

Gomes, T A, Rassi, V, MacDonald, K L, et al. (1991). Enteropathogens associated with acute diarrheal disease in urban infants in são paulo, brazil. The Journal of infectious diseases, 164(2), 331-7.

Gorter, A C, Sandiford, P, Pauw, J, et al. (1998). Hygiene behaviour in rural nicaragua in relation to diarrhoea. International Journal of Epidemiology, 27(6), 1090-100.

Greene, L E, Freeman, M C, Akoko, D, et al. (2012). Impact of a school-based hygiene promotion and sanitation intervention on pupil hand contamination in western kenya: A cluster randomized trial. The American journal of tropical medicine and hygiene, 87(3), 385-93.

Guerrant, R L, Hughes, J M, Lima, N L, et al. (1990). Diarrhea in developed and developing countries: Magnitude, special settings, and etiologies. Reviews of infectious diseases, 12 Suppl 1, S41-50.

Humphrey, J H. (2009). Child undernutrition, tropical enteropathy, toilets, and handwashing. Lancet (London, England), 374(9694), 1032-5.

Knight, S M, Toodayan, W, Caique, W C, et al. (1992). Risk factors for the transmission of diarrhoea in children: A case-control study in rural malaysia. International Journal of Epidemiology, 21(4), 812-8.

Kwiringira, J, Atekyereza, P, Niwagaba, C, et al. (2014). Descending the sanitation ladder in urban uganda: Evidence from kampala slums. BMC public health, 14, 624.

Liu, Li, Johnson, H L, Cousens, S, et al. (2012). Global, regional, and national causes of child mortality: An updated systematic analysis for 2010 with time trends since 2000. Lancet (London, England), 379(9832), 2151-61.

Luby, S P, Halder, A K, Tronchet, C, et al. (2009). Household characteristics associated with handwashing with soap in rural bangladesh. The American journal of tropical medicine and hygiene, 81(5), 882-7.

Mattioli, M C, Boehm, A B, Davis, J, et al. (2014). Enteric pathogens in stored drinking water and on caregiver. PLoS ONE, 9(1), e84939.

Mertens, T E, Jaffar, S, Fernando, M A, et al. (1992). Excreta disposal behaviour and latrine ownership in relation to the risk of childhood diarrhoea in sri lanka. International Journal of Epidemiology, 21(6), 1157-64.

Mock, N B, Sellers, T A, Abdoh, A A, et al. (1993). Socioeconomic, environmental, demographic and behavioral factors associated with occurrence of diarrhea in young children in the Republic of Congo. Social science & medicine, 36(6), 807-16.

Null, C, & Peprah, D. (2013). The SaniPath study: The consequences of a broken sanitation chain in low-income urban settings; sanitation conditions and behaviors (Conference presentation). American society of tropical medicine and hygiene annual meeting.

Peprah, D, Baker, K, Moe, C, et al. (unpublished paper) (2014). Public toilets and their customers in low-income, urban Accra, Ghana. Emory University, Atlanta, GA.

Phiri, K, Whitty, C J, Graham, S M, et al. (2000). Urban/rural differences in prevalence and risk factors for intestinal helminth infection in southern malawi. Annals of tropical medicine and parasitology, 94(4), 381-7.

Pickering AJ, Davis J, Walters SP, Horak HM, Keymer DP, et al. (2010) Hands, water, and health: fecal contamination in Tanzanian communities with improved, non-networked water supplies. Environ Sci Technol 44: 3267–3272. doi: 10.1021/es903524m

Pickering, A J, Julian, T R, Mamuya, S, et al. (2011). Bacterial hand contamination among tanzanian mothers varies temporally and following household activities. TM & IH. Tropical medicine and international health, 16(2), 233-9. doi 10.1111/j.1365-3156.2010.02677.x

Pickering, A J, Julian, T R, Marks, S J, et al. (2012). Fecal contamination and diarrheal pathogens on surfaces and in soils among tanzanian households with and without improved sanitation. Environmental science & technology, 46(11), 5736-43.

Prüss-Ustün, A, Bartram, J, Clasen, T, et al. (2014). Burden of disease from inadequate water, sanitation and hygiene in low- And middle-income settings: A retrospective analysis of data from 145 countries. TM & IH. Tropical medicine and international health, 19(8), 894-905.

SaniPath program document. *Unpublished data.* Exposure in public domains. The SaniPath study.

Schmidt, W, Aunger, R, Coombes, Y, et al. (2009). Determinants of handwashing practices in kenya: The role of media exposure, poverty and infrastructure. TM & IH. Tropical medicine and international health, 14(12), 1534-41.

Scott, B E, Lawson, D W, Curtis V. (2007). Hard to handle: understanding mothers' handwashing behaviour in Ghana. Health Policy Plan 22: 216–224.

Strina, A, Cairncross, S, Barreto, M L, et al. (2003). Childhood diarrhea and observed hygiene behavior in Salvador, Brazil. American journal of epidemiology, 157(11), 1032-8.

Strunz, E C, Addiss, D G, Stocks, M E, et al. (2014). Water, sanitation, hygiene, and soil-transmitted helminth infection: A systematic review and meta-analysis. PLoS Medicine, 11(3), e1001620.

Traoré, E, Cousens, S, Curtis, V, et al. (1994). Child defecation behaviour, stool disposal practices, and childhood diarrhoea in burkina faso: Results from a case-control study. Journal of epidemiology and community health, 48(3), 270-5.

Vasco, G, Trueba, G, Atherton, R, et al. (2014). Identifying etiological agents causing diarrhea in low income ecuadorian communities. The American journal of tropical medicine and hygiene, 91(3), 563-9.

Vujcic, J, Ram, P K, Hussain, F, et al. (2014). Toys and toilets: Cross-sectional study using children. TM & IH. Tropical medicine and international health, 19(5), 528-36.

Walker CL, Rudan I, Liu L, Nair H, Theodoratou E, et al. (2013) Global burden of childhood pneumonia and diarrhoea. Lancet 381: 1405–1416. doi: 10.1016/s0140-6736(13)60222-6

World Bank. (2011). Water supply and sanitation in Ghana: turning finance into services for 2015 and beyond. Water and Sanitation Program.

World Health Organization (WHO). (2010). Hidden cities: unmasking and overcoming health inequities in urban settings. Geneva, p: 13.

World Health Organization (WHO). (2014). Global health estimates 2014 summary tables. Retrieved from http://www.who.int/healthinfo/global_burden_disease/estimates/en/