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Household Determinants of Environmental Contamination in Northern Coastal Ecuador

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Household Determinants of Environmental Contamination in Northern Coastal Ecuador

By

Breanna Pennings

B.A., Calvin College, 2017

Thesis Committee Chair: Karen Levy, PhD, MPH

An abstract of
A thesis submitted to the Faculty of the
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Abstract

Household Determinants of Environmental Contamination in Northern Coastal Ecuador
By Breanna Pennings

Background: In developing countries, diarrhea is the second leading cause of death for children under five. Diarrhea may have a greater burden of disease than previously estimated. One cause of diarrhea, enteric bacteria, commonly enter the body through the mouth and can be acquired through contaminated food and water. This contamination can occur from human contact with animals, contact with the environment (i.e., soil, water), or contact with human feces. The northern coast of Ecuador has high levels of enteric pathogen transmission.

Goal: The purpose of this study was to answer the question: What household factors are associated with environmental contamination among households in Esmeraldas, Ecuador? The study aims are to describe the level of environmental contamination among households (Aim 1) and identify associations of household characteristics with environmental samples (Aim 2). Finally, we aim to assess the viability and feasibility of environmental sample collection and survey questions in order to inform future studies (Aim 3).

Methods: This was a descriptive study, which took place in Esmeraldas, Ecuador from June to August of 2018. Household characteristics (i.e., sociodemographic and household information) and environmental samples (water source, child's drinking water, mother's hand rinse, child's hand rinse, sentinel ball, sentinel duck, food preparation surface swab, and child's eating location swab) were collected from participating households.

Results: Using Pearson Correlation with $\log_{10}$ transformation, Mother's hand rinse *E. coli* counts were shown to be positively correlated with *E. coli* on food preparation location as well as the location were the child eats. The *E. coli* in household water sources were positively correlated with the child's drinking water (Aim 1). A paired-samples *t*-test showed that sentinel toy *E. coli* counts were higher in households who have stored water (Aim 2). The average time each same took to be fully processed was 9.53 minutes (not including the incubation time of 24hrs +/- 2hrs) (Aim 3).

Discussion: Exploratory analyses between environmental *E. coli* results and household characteristics support the conclusion that household characteristics influence contamination. Future research examining environmental contaminants in Ecuador should consider limitations with water collection and time needed to process samples via membrane filtration.

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Background

According to the World Health Organization (WHO), diarrhea is the second leading cause of death for children under five in developing countries, while evidence is increasing that diarrhea may have a greater burden of disease than previously estimated (Troeger et al., 2018). Severe diarrhea can deplete the body of necessary water and salts leading to severe dehydration and even death.

Mild-to-moderate episodes of diarrhea may also have negative developmental consequences. Diarrhea may be caused by enteric infections which can contribute to environmental enteropathy, a syndrome of intestinal inflammation and intestinal blunting of villi. The inflammation and nutrient malabsorption associated with environmental enteropathy may in turn lead to child growth faltering and poor cognitive development slower rate of height growth as well as weight gain (also known as growth faltering) in children (Rogawski & Guerrant, 2017). Poor nutritional status may further increase a child's risk of additional enteric infections (Guerrant, 2012) thus, creating a vicious cycle of "diseases of poverty".

The role of the microbiome within these processes is not fully understood, but it may moderate or exacerbate this cycle. The gut microbiome, a complex ecosystem of microorganisms, plays an important role in the development and regulation of host immunity (Hansen, 2014). It is believed that the microbiome is adapted through chronic and repeated enteric pathogen infections. A healthy gut microbiome is home to microorganisms that prevent the invasion of pathogens. Meanwhile an unhealthy gut microbiome may allow other harmful infections to occur, overwhelming commensal bacteria (Kamada, Chen, Inohara, & Nunez, 2013). As a result, it is important to understand the impact of individual enteric infections, but also chronic enteropathogenic exposure on the microbiome. It has been demonstrated that the gut microbiome is directly influenced by environmental factors (Spor, Koren, & Ley, 2011) but the association between enteropathogenic contamination of the household environment, where young children spend most of their time, and the gut microbiome, is not fully understood.

"Enteric bacteria typically enter the body through the mouth" and can be acquired through contaminated food and water (CDC, 2019). This contamination can occur from human contact with animals, contact with the environment (i.e., soil, water), or contact with human feces (CDC, 2019). As result, enteropathogenic exposure is assessed through sampling of these transmission pathways. Among these pathways, water is most often assessed using fecal indicator organisms to test for contamination (Gruber, Ercumen, & Colford, 2014).

In order to reduce enteric infections, it is necessary to identify household characteristics associated with environmental contamination. Identification of such characteristics can lead to public health interventions aimed at reducing environmental contamination and enteric infections.

Indicators of Environmental Contamination

Among children living in low and middle-income countries, between 68%-81% of severe diarrheal diseases are caused by enteric bacteria (Akuffo et al., 2017; Cajetan, Nnennaya, Casmir, & Florence, 2010). The current WHO guidelines recommend *Escherichia coli* (EC) and/or thermotolerant ("fecal") coliforms (FC) as indicators for disinfection process effectiveness, and as index organisms for the presence of fecal contamination and waterborne pathogens (Ashbolt, Grabow, & Snozzi, 2001). A systematic review and meta-analysis of the relationship between diarrheal illness and the presence of EC or FC indicators in household drinking water by Gruber et al. (2014) concluded that EC has a higher specificity for fecal contamination compared to FC. Furthermore, Levy et al (2012) found that childhood diarrhea in northern coast Ecuador was associated with levels of EC in drinking water, but not with concentrations of enterococci or somatic coliphage. In addition, diarrhea risk increases with moderate increases in EC contamination (Luby et al., 2015). Therefore, this thesis focuses on the use of EC counts as an indicator of environmental contamination.

Transmission Pathways

Water. Water is the most common enteric bacteria transmission pathway. Indicator organisms, such as EC, are most often used to assess water contamination (Gruber et al., 2014). A meta-analysis on the association of water supply type and fecal contamination of source and drinking water, published in 2015, found that the water quality deterioration between source point and stored water resulted in higher contamination of stored household water. The authors also stated that piped water was less likely to be contaminated (Shields, Bain, Cronk, Wright, & Bartram, 2015). However, a study by (Levy, Nelson, Hubbard, & Eisenberg, 2008) determined that water quality improved after water was transferred from a source (i.e. rainwater, tap, river, and stream), but then was re-contaminated in the home. Furthermore, availability of running tap water on premises is associated with reduced environmental contamination (Navab-Daneshmand et al., 2018). Although tap water has been classified as less contaminated, there are evidences that "improved" sources, such as tap water, still may be contaminated (Bain et al., 2014; Heitzinger et al., 2015). In 2014, the authors of a systematic review on exposure to fecal contamination through drinking water found that microbial contamination is "widespread and affects all water source types, including piped supplies" (Bain et al., 2014). Therefore, there is a need to examine the role of source water (i.e., the water a household uses for cooking, bathing, and everyday use), as well as, household and infant drinking water in relation to environmental sample contamination levels.

Compartments. Environmental compartments, such as hands, surfaces, and soils, are also associated with the transmission of enteric bacteria (Navab-Daneshmand et al., 2018). Hand contamination may directly affect human health through the transferal of pathogens to other compartments such as surfaces or directly into the mouth (Navab-Daneshmand et al., 2018). A study performed in Tanzania, reported that hand-to-mouth contact had a higher amount of ingested EC (97%) in comparison to stored drinking water (3%), therefore, hands were found to possibly be a source of human fecal contamination in stored drinking water as a result of possible cross contamination. However, due to the cross-sectional study design, directionality of contamination cannot be confirmed (Mattioli et al., 2014). In addition, a study in rural Bangladesh found a high prevalence of children putting contaminated objects in their mouths (Morita et al, 2017). Examining household characteristics such as animals in the home, sink location in the household, and whether there is water and soap available in relationship to environmental samples will inform possible hand contamination transferal.

Household characteristics. Household floors may contain contamination especially when household floors are made of soil, creating less of a boundary between the indoors and outdoors (Navab-Daneshmand et al., 2018). Examining wall and floor materials may serve as a proxy measure for possible soil contamination within the home, dependent on the material. In an in-depth observational study of households in Zimbabwe, infants were seen actively ingesting soil as well as chicken feces. In fact, infant play and feeding areas were frequently contaminated with fecal bacteria when households had chickens around (Ngure et al., 2013; Ngure et al., 2014). Similarly, households with animals in the home in peri-urban Harare, Zimbabwe showed significantly higher levels of EC (Navab-Daneshmand et al., 2018).

Furthermore, household size directly impacts water use; the greater the household size the more water is used. Household size also has both direct and indirect associations with household income and water use habits (Jorgensen, Graymore, & O'Toole, 2009). In a meta-analysis, country income level was statistically significant with water quality at the source; the higher the income, the greater the water quality (Shields et al., 2015), raising the question of whether individual household income may be associated with environmental quality. Yet, there is a gap in how social economic status (specifically the number living in the household, the number of rooms, and the average monthly income) potentially influences environmental contamination levels.

The northern coast of Ecuador has high levels of enteric pathogen transmission (Bhavnani, 2012; Vasco, 2014) and there is evidence that this transmission adversely impacts the growth of children in this region (Fuller, Villamor, Cevallos, Trostle, & Eisenberg, 2016).

Therefore, this thesis aims to answer the research question of: **what household factors are associated with environmental contamination among households in Esmeraldas, Ecuador?** This question's results will inform a larger cohort study, which aims to explore how environmental contamination impacts the gut microbiome. Potential characteristics of interest in the connection between environmental contamination and the gut microbiome, will be explored through addressing the three study aims. We hypothesize that less improved households (i.e. those with dirt floors, non-piped water, and lack of soap and/or water for hand washing) will have greater levels of EC contamination in the environmental samples. This thesis aims to answer this research question through describing the level of environmental contamination among households (Aim 1), identifying associations of household characterizes with environmental samples (Aim 2). Finally, we aim to assess the viability and feasibility of environmental sample collection and survey questions in order to inform future studies (Aim 3).

Methods

Study Design

This study is a primary data analysis from the Gut microbiome, enteric infections and child growth across a rural urban gradient (EcoMID) pilot study. The EcoMID pilot study's overall objectives were to characterize dietary and environmental exposures with the potential to influence the microbiome among mothers and children in northern coastal Ecuador and to validate survey instruments and sample collection methods that will later be used in the context of a larger cohort study. Individuals in Esmeraldas, Ecuador were recruited to participate in a pilot study, between June to August of 2018. The study site of Northern Coastal Ecuador provides an ideal location to examine interactions between the household characteristics and environmental samples. See Appendix A for further locational information.

Study Population

A total of 82 mother-child dyads were recruited into the pilot study. Due to the purpose of the pilot study being to test study methods, participants were recruited via convenience and snowball sampling, beginning with field worker's friends and family. Enrollment criteria for the dyads in the pilot study were: (1) mothers living in the Canton of Esmeraldas within the province of Esmeraldas, Ecuador; (2) self-report as Afro-Ecuadorian; (3) capable of proving consent; (4) over the age of eighteen; and (5) willing to answer all screening questions. In addition, (6) the child less than two years old and (7) developmentally 'normal' child with no known serious delays or health issues (e.g., congenital disorder).

Enrollment

Mothers were approached by field workers who described the study. If mothers expressed interest in the study, the fieldworkers began an informed consent procedure, after which the mother was invited to sign a consent form to indicate her willingness to participate on behalf of herself and her child. If the mother was illiterate, the consent form was read to her in the presence of a witness not involved in the study; the witness signed, and the mother provided a thumb print. Literacy was determined if the mother stated she could not read the form. Field workers were present for the form reading and the mother signed/marked in numerous places, providing consent for participation in the study, and environmental sampling. Ethical approval was granted by the University of Michigan Institutional Review Board and Emory University (IRB).

After obtaining consent, field workers collected mother and child demographic data and household information. Field workers read the questions to the mother and entered the data/responses a tablet using Open Data Kit (ODK), a free, open-source software used in resource-constrained environments for collecting, managing, and using data (opendatakit.org). Environmental samples were collected by the field worker on the second visit, at minimum two days after the first visit (on average four days after consent was given).

Measures

Household characteristics. Open Data Kit (ODK) surveys were created by study leaders pre-pilot study and used to collect data on sociodemographic and household information. Field workers input mother's responses to questions, or their own observations, onto ODK forms on Android tablets.

The following household characteristic were chosen based on prior literature supporting their association with environmental contamination: number of people in the household, number of rooms in home, household water source, household drinking water source, if water is stored, water treatment method, child's drinking water source, child's drinking water treatment methods, home ownership, household possessions, cooking fuel source, ownership of agricultural land, and having a bank account were reported by the mother. If animals are in the home, washing station visible, sink having soap and/or water, floor material, and wall material were observations filled in by the field worker. Appendix B lists each household variable of interest and response values.

Environmental samples. Eight types of environmental samples were obtained: household source water, child's drinking water, ball sentinel toy, duck sentinel toy (discontinued mid-study), mother's hand rinse, child's hand rinse, food preparations swab, and the child's eating location swab. The two water samples were collected using 100mL WhirlPak bags (Nasco, Fort Atkinson, WI) from the household water source and the source of water from which the child drinks. The hand rinses, (one of the mother's hands and one of the child's hands) were performed using 500mL of distilled water for 30 seconds per hand. Mothers were asked to scrape under their nails and rub between their fingers, then the field worker messaged their hand for the remainder of the time to insure the removal of material on hands. Children were directed to wiggle their fingers if able, then after, the field worker messaged the hand. If the child was unable to wiggle their fingers, the field worker solely messaged the hand for the 30 seconds. A sentinel toy was placed in each household for a minimum of 24 hours (maximum of 48hrs). The field worker would return to rinse the ball for 30 seconds, in 300mL of water, making sure to message it thoroughly. After this, the toy was returned to the mother as a gift. Two surface swabs were taken using individually wrapped sterile cotton tipped swabs. One surface swab was taken from where the mother prepares food for the child and the other was from the location the child eats. A 20x20 centimeter square stencil was used to guide the swabbing protocol. The swab was wiped across the surface in the following order: left to right across the surface, top to bottom, upper left corner to the bottom right, and finally the upper right corner to the bottom left corner. The swab was then put into a 100mL WhilPak bag of distilled water. All samples were stored on ice in a cooler until transported to the lab and were processed within 6 hours of collection. Sterile surface swabs and distilled water were purchased from the hospital supplier. Additional distilled water used for the control, hand rinses, and sentinel toy rinse was purchased from a local grocery store.

Sample Processing

Household characteristics. The household characteristics data were cleaned using the R software for statistical analysis version 1.1.423 (R Core Team, 2013) to create final versions of the data. ODK responses from repeated households were merged, incorrect coded homes were corrected based on visit date and filed paperwork by the field worker, and incorrect codes were amended when possible. Household characteristics of focus were chosen based on literature evidence of factors that influence contamination levels of drinking water.

Environmental samples. All environmental samples were processed following a standardized membrane filtration method with a stainless-steel funnel, using an adapted U.S. EPA Membrane-filter technique method 1603 (EPA, 2014) with Compact Dry™ EC medium. Each plate was labeled with an identification number, date, and time incubated. The media was hydrated using 1mL of the sample liquid and the membrane filter was placed grid side up directly on the media after 100mL of sample water was run through. The sample was then incubated for 24-hours +/- 2 hours, in a Hova-Bator 1602N Thermal air, 46 egg, Styrofoam incubator (Savannah, Georgia, USA) set to 37 degrees Celsius and checked each day at the beginning and end of protocol process. The Compact Dry™ EC dish was removed from the egg incubator, time was recorded, and colonies were counted by a single individual after 24 hours of incubation. Blue colonies indicated *E. coli*, red/pink/purple colonies indicated fecal coliforms, and other bacteria colonies grew a yellowish or colorless. Appendix C shows a sample's bacteria growth on a Compact Dry™ EC plate with each colony type indicated via arrows.

Statistical Analysis

Data were analyzed using SAS 9.4 (32) (English) and graphed using IBM SPSS Statistics 25. The term "household characteristics" refers to the information collected from each household using ODK forms. "Environmental samples" refers to the samples taken within each home, while *E. Coli* (EC) counts are the bacteria colony counts of the samples. Mean and standard deviation were reported for continuous variables while number and percentage were reported for categorical variables. Results were considered statistically significant at a level of $p \leq 0.05$.

Eighty-two mother-child dyads were enrolled in the pilot study. Sixty households completed household characteristic forms over the course of eight weeks. In total, 47 households participated in environmental sampling. This sample size is smaller than initially proposed; however, still provides reasonable descriptive data to inform the larger study.

Aim 1. To describe the level of environmental contamination among households, all environmental samples were summarized using established drinking water cut points. Based on the World Health Organization standards, drinking water was considered safe if <1 colony forming units (CFU) EC was detected in a 100-mL sample (WHO, 2008). The distribution of source and stored drinking water samples were stratified by the WHO EC risk categories: low risk/safe (< 1 EC/ 100 mL), intermediate risk (1–10 EC/100 mL), high risk (11–100 EC/100 mL), and very high risk (> 100 EC/100 mL) for human consumption (WHO, 2011). Categorical variables were created based on these cut points.

To explore environmental reservoirs such as sentinel toys, maternal and child hand rinses, and surfaces, all of which have been shown by prior studies to be potentially important exposure routes to enteric pathogens, specifically EC (Mattioli, Davis, & Boehm, 2015; Morita et al., 2017). The drinking water cut points were used for the other environmental samples which were not ingested water i.e., the mother and child hand rinses, the sentinel toy rinses, and the surface swabs of food preparation location and child's eating location. All cut points were individually explored using basic summary statistics with frequencies of each risk group by environmental sample. Although these cut points were used, they do not have the same interpretation (relationship to diarrheal disease) as the water samples. Households were separated by EC count range as Low Risk, Intermediate risk, High risk, and Very high risk, according to the WHO drinking water standards.

The relationships between environmental samples were explored using Pearson Correlations using $\log_{10}$ transformations of all environmental samples EC counts. Log_{10} transformations were since the environmental EC sample counts were skewed. When EC counts were zero, the rate of 0.5 was used for $\log_{10}$ transformations, this was used as it was half of the detection rate of membrane filtration which is one bacterial colony counted. Pearson Correlations, measures the degree of linear relationships between two variables using the following formula:

$$\rho = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{(n-1)\ s_x s_y}$$

Aim 2. To examine associations between of household characteristic with environmental samples, the $\log_{10}$ of the environmental samples were used for all statistical tests. *T*-tests were used to determine any possible relationships between the continuous $\log_{10}$ transformed environmental samples with the two-level household characteristics (i.e., Yes/No responses for: stored water, animals in home, washing station, soap, and water). There are three key assumptions when using *t*-tests which need to be accounted for: same variance, normal distribution, and independent variables. To account for the unequal variances and non-normal distribution in the data, the Satterthwaite *t*-test was used with $\log_{10}$ transformations; all $\log_{10}$ EC measures were assumed to be independent variables. Although multiple *t*-tests were conducted, no correction for multiple testing was made, due to the preliminary nature of the study.

For household characteristics that were multi-level responses, dichotomous variables were created (Yes/No), see Appendix D for original coding with new variable coding. All water treatment responses were dichotomized based on the methods ability to be effective against EC. All larvicide only responses were coded as “No” while all responses with boiling and/or chlorine treatment listed were coded as “Yes.” Larvicide was categorized as a non-effective treatment in reducing EC, due to its characteristic of targeting mosquito larvae and not killing EC (EPA, 2016). Source water, household drinking water, and the child’s drinking water source were also recoded as a two-level variable of “Improved” or “Unimproved.” (see Table 1)

Table 1: Improved and Unimproved Drinking Water Sources

Improved	Unimproved
Piped household/neighbor water connection	Unprotected well or spring
Public Tap/standpipe	Surface water
Borehole	Cart with small tank/drum
Protected well or spring	Tanker truck
Rainwater collection	Bottled water
Bottled water	

Referenced from WHO Progress on drinking water and sanitation 2017 edition WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation.

Aim 3. Viability and feasibility for measurements and survey questions, was examined using descriptive statistics of process variables. These process variables included the length of time to: collect a sample, process the sample, and read the results as well as, factors preventing sample collection and overall cost per sample.

Results

Study Flow

As depicted in Figure 1, 82 dyads were assessed for eligibility in the pilot study of which 68 enrolled. Fourteen were not willing to participate. Sixty households provided enrollment basic information and 58 households completed the household characteristic data; eight households were loss to follow-up. Environmental samples were taken at 47 households. Of the 47 households in which environmental samples were taken (note: four households completed the environmental samples but had incomplete household characteristic data) leaving a sample size of 43 households.

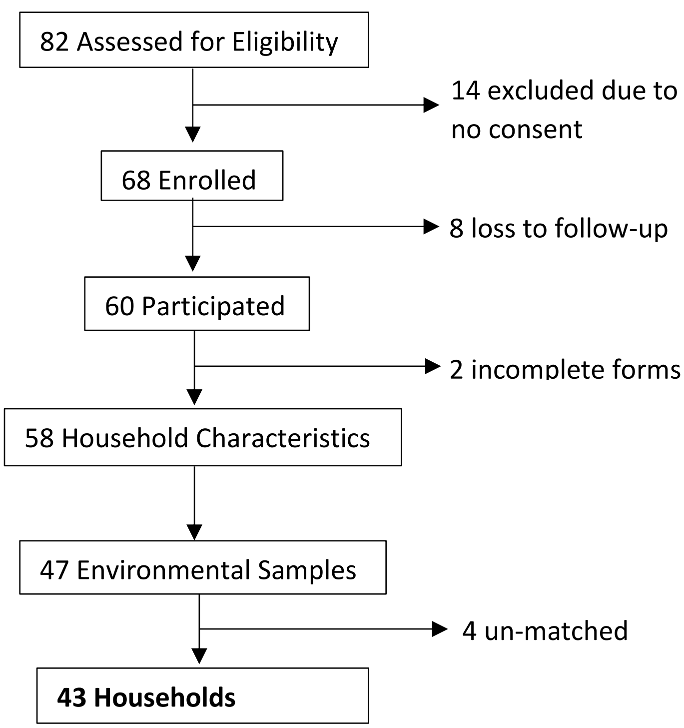


Figure 1. Pilot study enrollment information

Household Characteristics

Of the 43 households participating in the pilot study with both environmental samples and household characteristics data, the majority lived in the 15 de Marzo neighborhood (56.8%; *n*=25). The second most represented neighborhood was Barrio las Americas at 13.6% (*n*=6). Children were enrolled composed of 51.2% females (*n*=21) and 48.8% males (*n*=20). Appendix E shows graphical depictions of the categorical dyad statistics. Table 2 shows additional characteristics of the mother-child dyad.

Table 2. Descriptive Statistics

Variable	*N*	Minimum	Maximum	Mean	Std. Deviation
Child's Age in Days	42	9	714	315.02	178.75
Mother's Age in Years	14	17	34	24.43	4.96
Age Married	42	13	26	18.76	3.49
Age Pregnant	43	14	26	18.37	3.33
Number of Pregnancies	43	1	7	2.49	1.53
Number of Children	43	1	7	2.09	1.19

Note: Age pregnant is the age at which the mother was at the time of her first pregnancy. The first pregnancy is not necessarily the child enrolled in the study. Mother's age's in years is missing variables due to this question being added mid-way through the study.

Aim 1

All environmental sample blanks were negative for EC, FC, and other bacteria, indicating no cross-contamination while processing samples. Pearson Correlation with $\log_{10}$ transformation was assessed between each of the EC environmental samples taken see Figure 2. A statistically significant positive correlation was found between EC from household water source and EC from child's drinking water ($r = 0.55$; $p < 0.0001$; *n*=38). Mother's hand rinse EC and food preparation location EC ($r = 0.31$; $p = 0.0379$; *n*=46) as well as mother's hand with the EC and the location where the child eats ($r = 0.38$; $p = 0.0371$; *n*=31) showed positive correlation. No other statistically significant correlations were found between environmental samples. Figure 3 shows the environmental samples with the number of households by risk group.

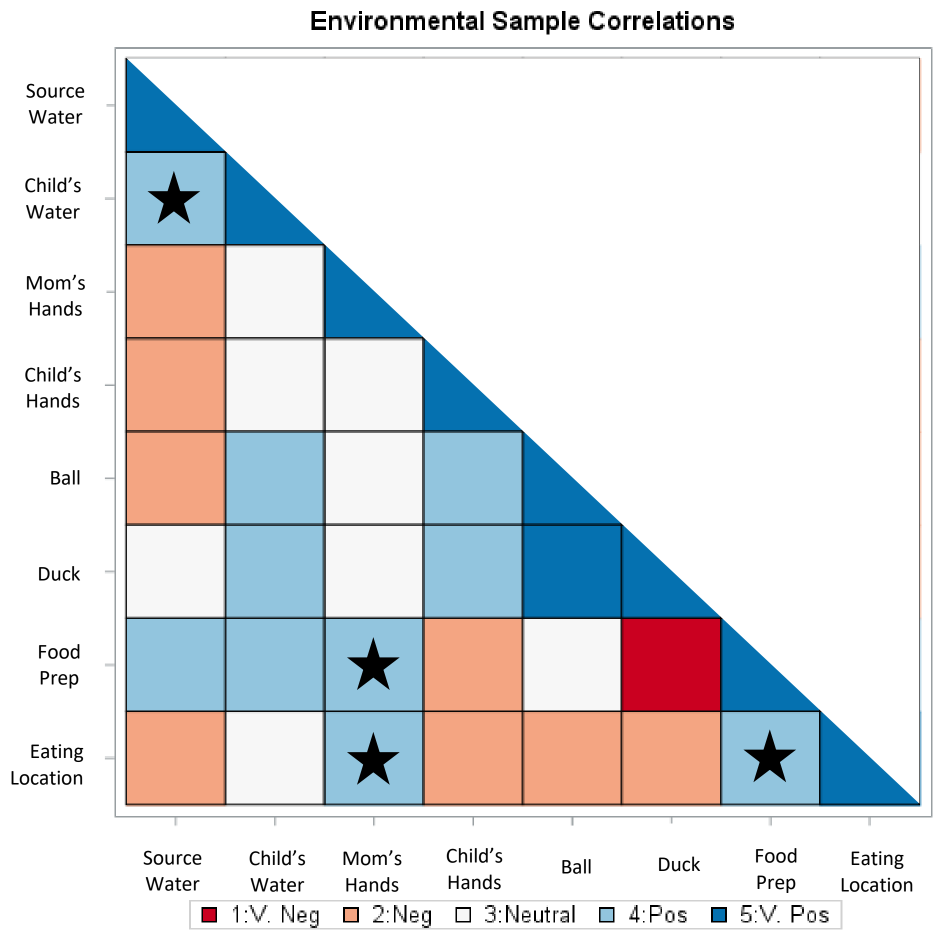


Figure 2: Stars represent a p-value < 0.05, all results are based on the $\log_{10}$ EC counts. Very Negative: Correlations in the range (-1, -0.6). Negative: Correlations in the range (-0.6, -0.2). Neutral: Correlations in the range (-0.2, 0.2). Positive: Correlations in the range (0.2, 0.6). Very Positive: Correlations in the range (0.6, 1).

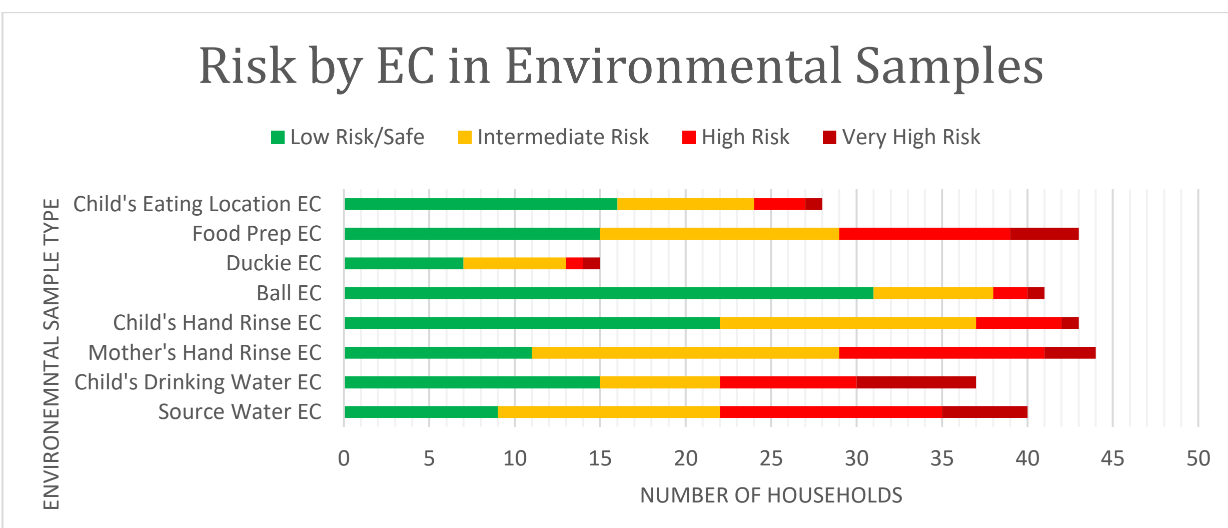


Figure 3. Frequency of each risk group classification by the WHO standards for each environmental sample (WHO, 2008).

Aim 2

A paired-samples *t*-test was conducted to compare dichotomous household characteristic counts, with the EC counts from the environmental samples (see Appendix F). The sentinel toy ball EC counts were significantly higher ($t(36)=-2.57$; $p=0.0144$) in households who have stored water ($M= -0.0211$, $SD=0.6623$) compared to households without stored water($M= -0.3010$, $SD=0$). There was no statistical difference in the EC counts and whether the household had animals indoors. EC from source water, child's drinking water, duckie sentinel toy, and food prep location were statistically significant with ownership of agricultural land, as shown in Table 3.

Of the three continuous household characteristics considered (number of people living in a household, number or rooms in a household, and monthly income), there was no statistically significant association between household characteristics and any of the $\log_{10}$ EC counts. Of note, a weak positive correlation was found between the number of people living in a household and the monthly income ($r= 0.29472$; $p=0.0247$; $n=59$) using Pearson Correlation.

Aim 3

To examine the feasibility of the data collection methods, the average time each sample took throughout the sample protocol stages (sample collection, sample processing, and reading results) is described (see Table 2). Sample processing took the greatest number of minutes ($M=5.45$).

Table 3. Time Processing

Time taken in minutes:	Mean	Maximum	Minimum
Sample Collection	2.35	7.40	1.00
Sample Processing	5.45	16.00*	1.50
Reading Results	1.73	10.50*	0.50
Full Process	9.53^{+}		

All results reported in minutes/individual sample. *Indicates training days with higher than normal time required to explain the process. + Indicates predicted total time to process a single sample, not including the incubation time of 24hrs +/- 2hrs.

Three households were unable to have source water sampled due to water outages and unavailability of the field worker to circle back post outages the field workers had already visited three times. Nine households were missing the child's drinking water source, with five being due to not having the water prepared (i.e. boiled; *n*= 5) and children too young to drink water and/or were solely fed with breast milk not formula (*n*= 4). Two households did not have the child's hand rinse due to the child being asleep. Three sentinel toys were not given to households, while two households lost the toy within 48hrs. One household refused the food preparation surface swab as well as the child's eating location swab. Ten children were not eating solid food yet, so the child's eating location was not able to be collected and five children ate on their mother's lab, which was not swabbed. See Appendix G for detailed depictions.

Discussion

The level of environmental contamination among household, was addressed through categorizing environmental contamination among households by exploring relationships among environmental samples within households (Aim 1). We found a positively linear relationship between mother's hands and both food preparation location and child's eating locations. However, in general, the majority of environmental samples were not strongly correlated with each other, perhaps suggesting that each test provides unique, and potentially complementary information. These results suggest that to fully characterize the child's environment, testing of multiple potential transmission pathways is advantageous.

Through the results of the t-tests, aim 2 of identifying associations of household characteristics with environmental samples was achieved. The statistical hypothesis of all each *t*-test is that there would be in no change in the EC results from the household characteristics. The statistical significance between increased EC counts in child's drinking water and unimproved child's drinking source was consistent with previous literature that unimproved sources having higher EC counts (Shields et al., 2015). Surprisingly there was no statistical significance between the household water source and the EC count from the household water source. This potentially could be due to the limited samples size and would require further research to hypothesize the lack of relationship.

Although there were limitations due to the small sample size, exploratory analyses between environmental sampling results and household characteristics support the conclusion that household factors influence contamination. We found that child's drinking water was more likely to be contaminated among those with (M= 0.0428, SD=0.6460) and without (M= 1.1225, SD=1.1686) a washing station; t(32)=2.85, p=0.0076. As well as the results between the duck sentinel toy with (M= 0.4758, SD=0.9111) and without (M= -0.3010, SD=0) water in the sink; t(12)=-3.07, p=0.0096, which could be due to the limited sample size of the duck. The ball sentinel toy with and without stored water, as mentioned in the results section, may indicate a potential household characteristic.

Limitations

The small sample size of this pilot study was a key limitation, as well as the unequal sample sizes between the household characteristic and the environmental samples. This study was focused on developing and testing feasibility of field methods, rather than hypothesis testing. Furthermore, the study was constrained by time as the research team was only in Ecuador for the summer. The time constraint prevented further enrollment of mother-child dyads. Nevertheless, these preliminary results suggest several potential avenues for future investigation.

Throughout the study, there were numerous water access issues ranging from weeklong outages, to pipes being disconnected, to the municipality inputting water meters at each home. Therefore, highlighting the difficulties of conducting water research in areas experiencing water access limitations. This study underrepresents the number of household's that missed household source water collection due to outages, as the research team would circle back to household when water was back in service. This finding is relevant for future study logistics, as collecting constant water source samples was a challenge. These results also suggest that there is a need for further characterization and understanding of the impact of water insecurity in this urban study site.

Assessing the child's drinking water also proved challenging. Most households reported separately preparing drinking water for their child. However, many households only treated, made, and/or bought this water as needed. There is a need to better understand this practice, in particular, to understand how consistently, and effectively, household prepare safe drinking water for their young children.

Another key limitation of this pilot study was the time requirements for sample processing. Each sample had to be collected in the community, transported back to the laboratory, and processed within eight hours. Processing was completed by one individual. While this enhanced consistency among EC results, it also limited the number of samples in which could be collected in a day. Field workers had to balance enrolling new dyads into the study while making the needed appointments with those currently enrolled, this led to fluctuations in enrollment. This significant person-time required to complete household assessment via the membrane filtration method has led study investigators to move to a less labor-intensive method of environmental assessment, using Petrifilms, for the primary cohort study.

Within the household characteristic collection process there was the potential for respondent bias, as the mothers answered many of the questions knowing the purpose of the study, which is not necessarily a hinderance. Another possible route for bias (confirmation bias) was when field workers reported observations. This limitation is not unusual and is shared by most such studies in more rural areas.

Study results should be interpreted with caution as the results focus on potential correlations/relationships and not casual effects. Additional longitudinal research is needed to determine causation (i.e. whether household characteristics directly lead to more contaminated environments).

The dichotomization of variables may influence the study findings. For instance, households with unimproved domestic water sources who used bottled water as the main drinking water source were recoded as having unimproved drinking water, while households with improved sources using bottle water for drinking were classified as improved. Although the Joint Monitoring Program recently moved tanker trucks into the improved categorization, based on community accessibility, availability, and quality the unimproved label was still used for households who used tanker trucks based on WHO drinking water guidelines (JMP, 2018).

Recommendations

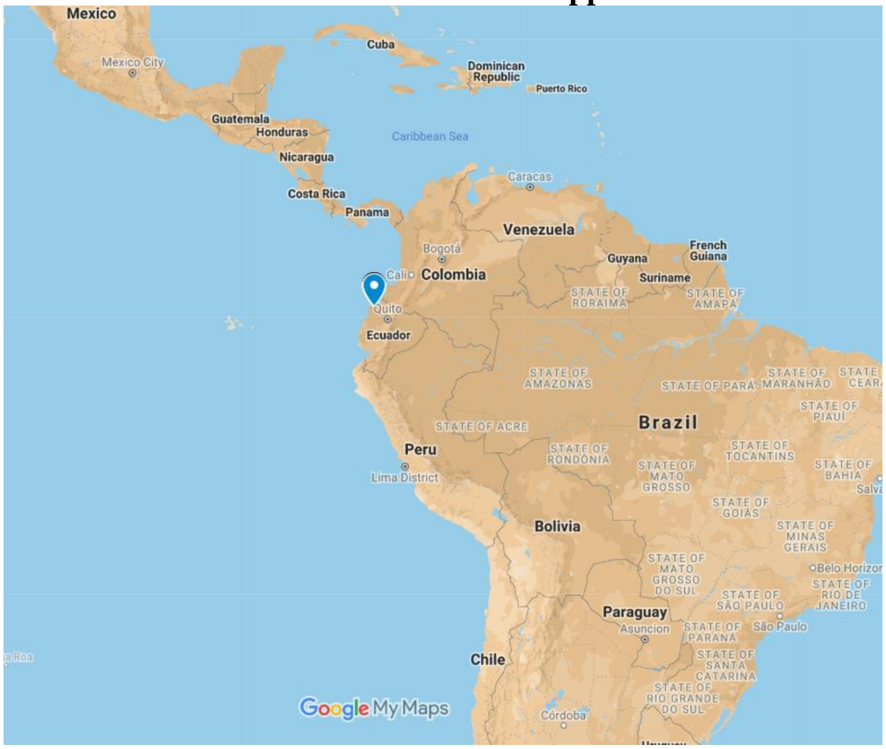
In addressing Aim 3, focusing on the implications of the results and how they inform the larger study there are a few key recommendations. First, although more than one kind of environmental sample was useful in characterizing household exposure, some samples were more burdensome to collect than others, were not association with household contamination, and might therefore be dropped in future sampling efforts. Specifically, the food preparation location swabs and eating location swabs seem to be relatively insignificant in classifying household contamination. The mother's hands were shown to be associated with both the food preparation location and the child's eating location. The hand samples have the potential to classify household contamination as they are what touch the environmental and numerous children have many hand-to-mouth moments. The sentinel toys provided very little information on the household contamination level as they often were not properly used: mothers would keep the toy from the child, would not give the toy, and were easily lost. Overall both sentinel toys remained relatively low risk for EC contamination, however, this may be due to the small sample size.

Second, the time each sample took to be processed changed based on the filter availability; samples required less time to process when all three filters were clean. When filter apparatuses needed to be sterilized, additional time was added to the processing speed, as it was necessary that the filter apparatus be cool before processing the sample. A key benefit of having a space in the hospital laboratory, was that air flow was constant, allowing the filter apparatus to cool quicker than if it was done in a non-airconditioned space. This would be a key limitation if this process was done in the field rather than a laboratory.

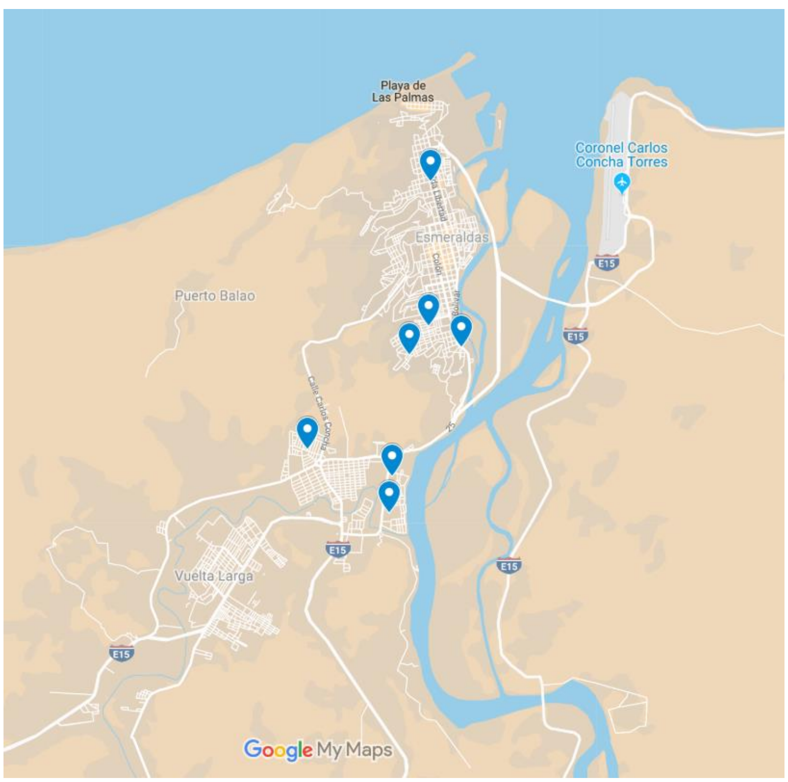
Conclusion

In conclusion, among a sample of households in northern costal Ecuador, EC was found in environmental samples in numbers exceeding recommendation by in many households. Results showed possible interaction of household characteristics with environmental samples. We also found that the protocol of environmental sampling was difficult due to challenges obtaining samples and time needed sample processing. Future research should incorporate this type of sampling method when resources are available, if not seek alternative methods. Although this study represents the first step in identifying household determinants of environmental contamination, further research is needed to elucidate the relationship.

Appendix A



Norther Coastal Ecuador pilot study location; created using Google MyMaps.



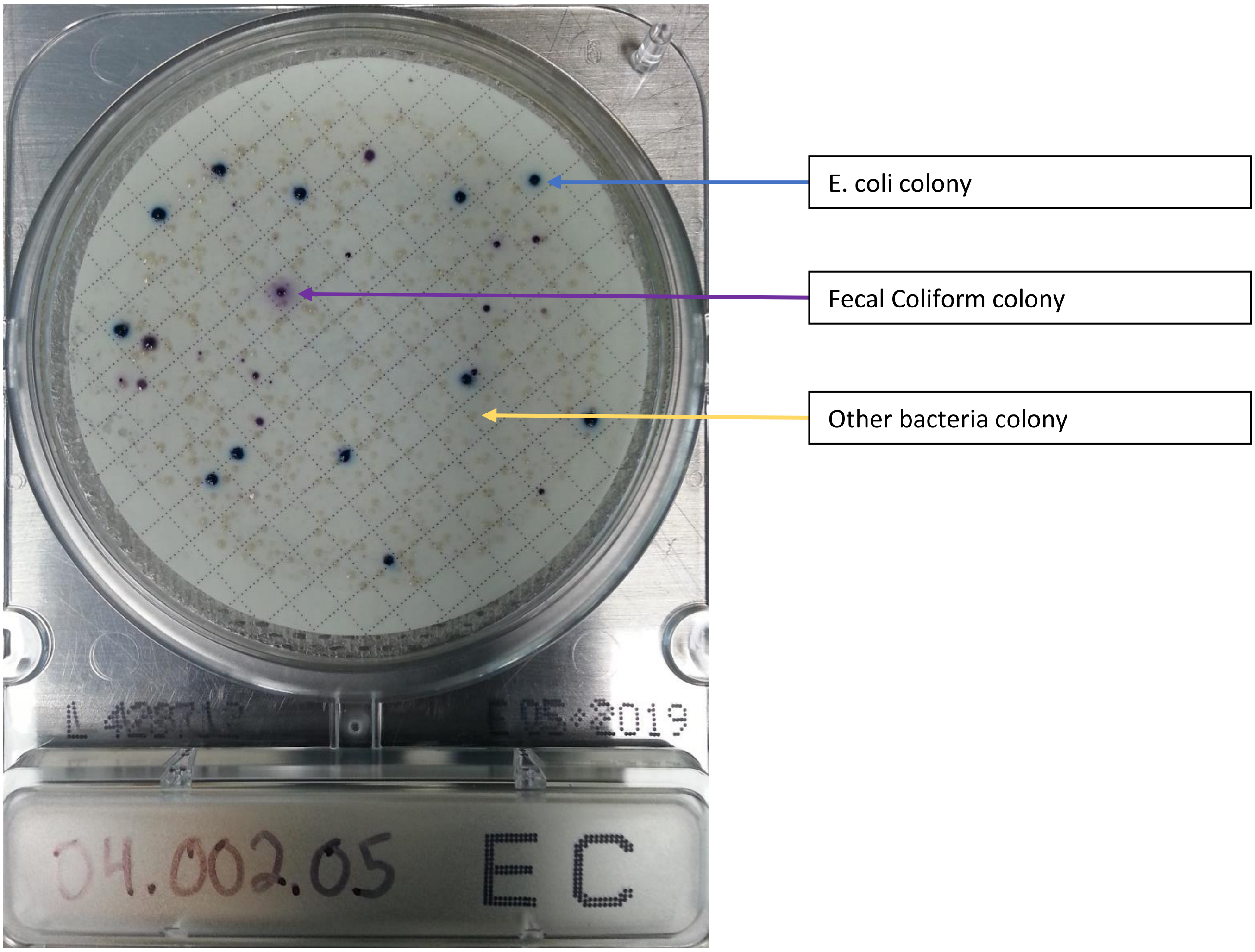
Site locations within in Esmeraldas, Ecuador; created using Google MyMaps.

Appendix B

Form	Household code	Meaning	Coding/Choices
Form D1	HH#	Household ID code	##M###
	numpeople	Number of people living in each household	#
	numrooms	Number of rooms in each home	#
	Watersource	Household water source	1. Well / tube well; 2. Protected excavated well; 3. Unprotected excavated well; 4. Protected spring; 5. Unprotected spring; 6. Surface water - river; 7. Stream water surface stream; 8. Piped water connection inside the house; 9. Piped water connection outside the house (in the yard); 10. Neighbor's piped water connection; 11. Public tap; 12. Small tank truck / drum; 13. Tank truck; 14. Rain water; 888. Other
	Drinkwatersource	Household drinking water source	1. Well / tube well; 2. Protected excavated well; 3. Unprotected excavated well; 4. Protected spring; 5. Unprotected spring; 6. Surface water - river; 7. Stream water surface stream; 8. Piped water connection inside the house; 9. Piped water connection outside the house (in the yard); 10. Neighbor's piped water connection; 11. Public tap; 12. Small tank truck / drum; 13. Tank truck; 14. Rain water; 15. Bottled water; 16. cistern; 888. Other
	Storedwater	Water stored in household	1. No; 2. Yes
	Txwater	Household drinking water treatment method	1. Boil it; 2. Chlorine; 3. Filter; 4. UV light; 5. Larvicida (abate); 6. Settle; 7. Boil and Chlorine; 8. Boil and Larvicida; 9. Chlorine and Larvicida; 10. Boil, Chlorine, & Larvicida; 888. Other (describe)
	Childwater	Child’s drinking water source	1. Well / tube well; 2. Protected excavated well; 3. Unprotected excavated well; 4. Protected spring; 5. Unprotected spring; 6. Surface water - river; 7. Stream water surface stream; 8. Piped water connection inside the house; 9. Piped water connection outside the house (in the yard); 10. Neighbor's piped water connection; 11. Public tap; 12. Small tank truck / drum; 13.

			Tank truck; 14. Rain water; 15. Bottled water; 888. Other
	Txchildwater	Child's drinking water treatment method	1. Boil it; 2. Chlorine; 3. Filter; 4. UV light; 5. Larvicida (abate); 6. Settle; 7. Boil and Chlorine; 8. Boil and Larvicida; 9. Chlorine and Larvicida; 10. Boil, Chlorine, & Larvicida; 888. Other (describe)
	animals	Animals in household	1. No; 2. Yes
	Washingstation	Washing station in household	1. No; 2. Yes
	Sinkwater	Water available in household	1. No; 2. Yes
	Sinksoap	Soap available in household	1. No; 2. Yes
	Floormat	Floor material	1. Earth / sand; 2. Manure; 3. Wooden boards; 4. Palm / bamboo; 5. Parquet or polished wood; 6. Vinyl or asphalt; 7. Ceramic tiles; 8. Cement; 9. Carpet; 888. Other
	Wallmat	Wall material	1. Walls without hay; 2. Reed / palm / tree trunks; 3. Earth; 4. Bamboo with mud; 5. Stone with mud; 6. Adobe discovered; 7. Plywood; 8. Cardboard; 9. Reused wood; 10. Cement; 11. Stone with lime / cement; 12. Bricks; 13. Cement blocks; 14. Adobe covered; 15. Wood planks / wooden shingles; 16. Plastic; 888. Other
Form D2	Ownhome	Ownership of the home	1. Owner; 2. Rented; 3. Borrowed; 4. Inheritance; 888. Other
	HHpossess	Possessions of the household	1. Electricity; 2. Radio; 3. Non-mobile phone; 4. Microwave; 5. Television; 6. Refrigerator; 7. Computer; 8. Wristwatch; 9. Internet; 10. Mobile phone; 11. Bicycle; 12. Motorcycle; 13. Scooter; 14. Carriage pulled by animals; 15. Car or truck; 16. Boat with an engine
	Cookingfuel	Cooking fuel type of the household	1. Electricity; 2. LPG; 3. Natural gas; 4. Biogas; 5. Kerosene; 6. Coal, lignite; 7. Charcoal; 8. Wood; 9. Straw / Shrubs / Grass; 10. Agricultural cultivation; 11. Animal excrement; 777. Food is not cooked at home; 888. Other
	Agrland	Household owning agricultural land	1. No; 2. Yes
	Bankaccount	Household having a bank account	1. No; 2. Yes

Appendix C


E. coli colony
Fecal Coliform colony
Other bacteria colony
04.002.05
EC

Appendix D

Household code	New Code	Original Code
Watersource	Improved	1. Well / tube well; 2. Protected excavated well; 4. Protected spring; 8. Piped water connection inside the house; 9. Piped water connection outside the house (in the yard); 10. Neighbor's piped water connection; 11. Public tap; 14. Rain water; 888. Other
	Unimproved	3. Unprotected excavated well; 5. Unprotected spring;6. Surface water - river; 7. Stream water surface stream; 12. Small tank truck / drum; 13. Tank truck;
Drinkwatersource	Improved	1. Well / tube well; 2. Protected excavated well; 4. Protected spring; 8. Piped water connection inside the house; 9. Piped water connection outside the house (in the yard); 10. Neighbor's piped water connection; 11. Public tap; 14. Rain water; 15. Bottled water; 16. cistern; 888. Other
	Unimproved	3. Unprotected excavated well; 5. Unprotected spring; 6. Surface water - river; 7. Stream water surface stream; 12. Small tank truck / drum; 13. Tank truck; 15. Bottled water
Txwater	Yes	1. Boil it; 2. Chlorine; 3. Filter; 4. UV light; 6. Settle; 7. Boil and Chlorine; 8. Boil and Larvicide; 9. Chlorine and Larvicide; 10. Boil, Chlorine, & Larvicide
	No	5. Larvicide (abate); 888. Other (describe)
Childwater	Improved	1. Well / tube well; 2. Protected excavated well; 4. Protected spring; 8. Piped water connection inside the house; 9. Piped water connection outside the house (in the yard); 10. Neighbor's piped water connection; 11. Public tap; 14. Rain water; 15. Bottled water; 888. Other
	Unimproved	3. Unprotected excavated well; 5. Unprotected spring; 6. Surface water - river; 7. Stream water surface stream; 12. Small tank truck / drum; 13. Tank truck; 15. Bottled water
Txchildwater	Yes	1. Boil it; 2. Chlorine; 3. Filter; 4. UV light; 6. Settle; 7. Boil and Chlorine; 8. Boil and Larvicide; 9. Chlorine and Larvicide; 10. Boil, Chlorine, & Larvicide
	No	5. Larvicide (abate); 888. Other (describe)

Appendix E

Neighborhood

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	15 de Marzo	25	56.8	58.1	58.1
	Barrio las americas	6	13.6	14.0	72.1
	Aire libre	5	11.4	11.6	83.7
	Tiwinza	1	2.3	2.3	86.0
	Propicia 1	1	2.3	2.3	88.4
	Other	5	11.4	11.6	100.0
	Total	43	97.7	100.0	
Missing	System	1	2.3		
Total		44	100.0		

Job Type

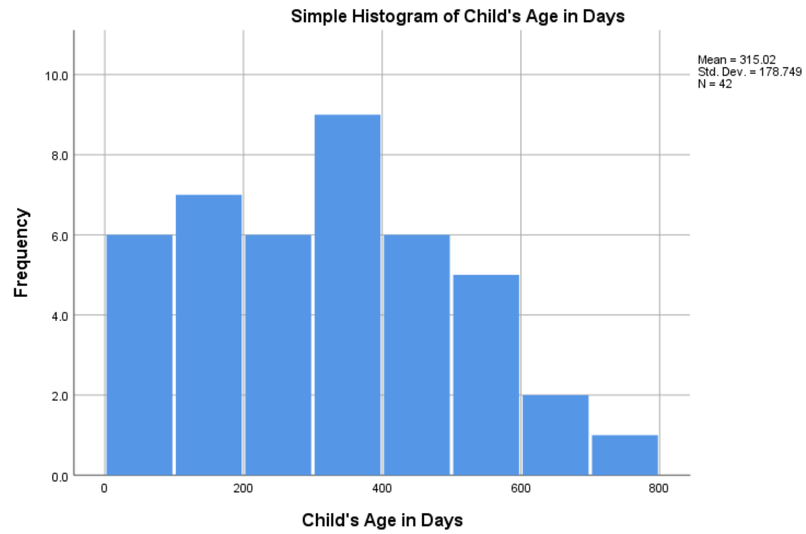
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Own house / Housewife	32	72.7	74.4	74.4
	Student	9	20.5	20.9	95.3
	Business	1	2.3	2.3	97.7
	Teacher	1	2.3	2.3	100.0
	Total	43	97.7	100.0	
Missing	System	1	2.3		
Total		44	100.0		

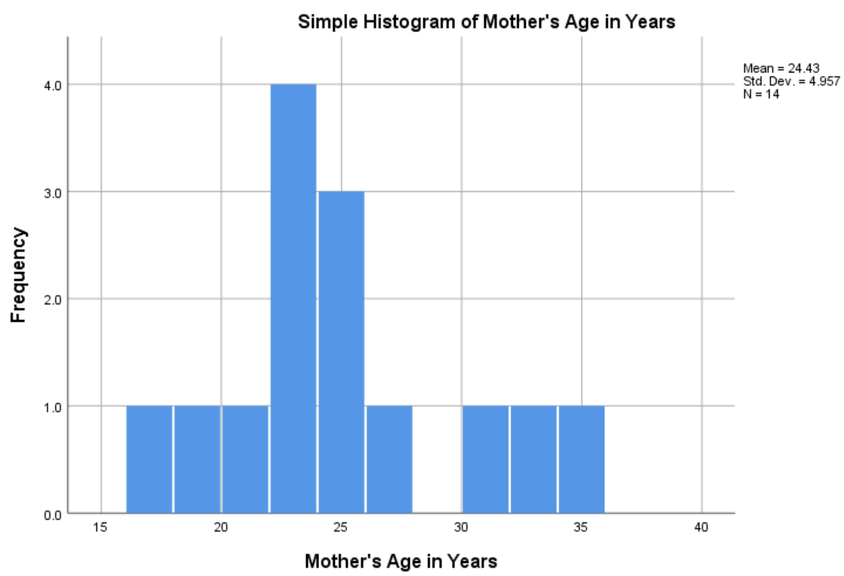
Marital Status

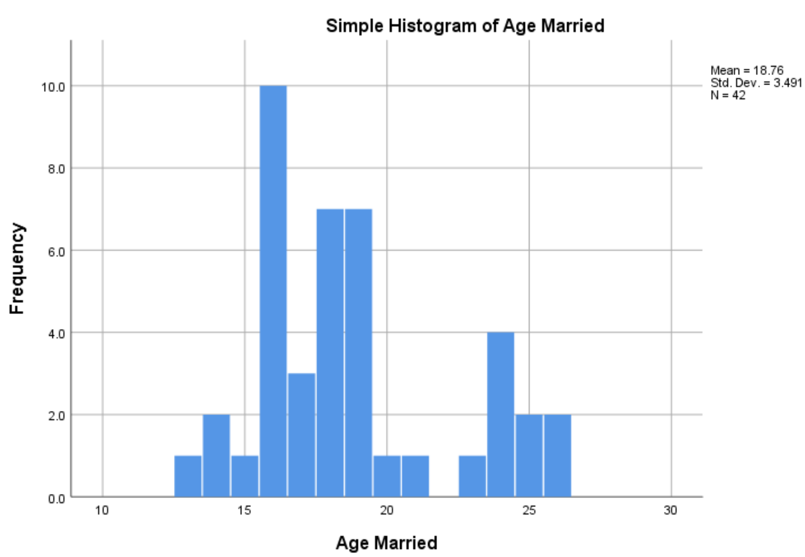
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Married/ free union/ living together	24	54.5	55.8	55.8
	Divorced / separated	2	4.5	4.7	60.5
	Single / never married	17	38.6	39.5	100.0
	Total	43	97.7	100.0	
Missing	System	1	2.3		
Total		44	100.0		

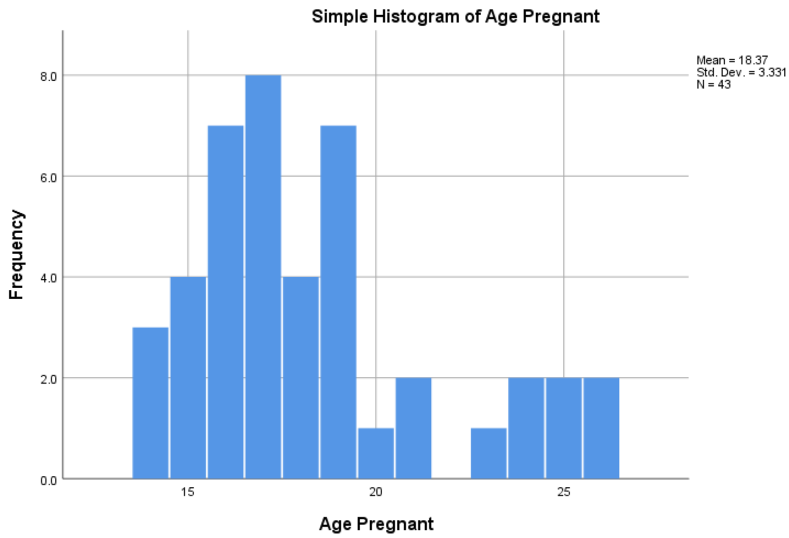
Child's Sex

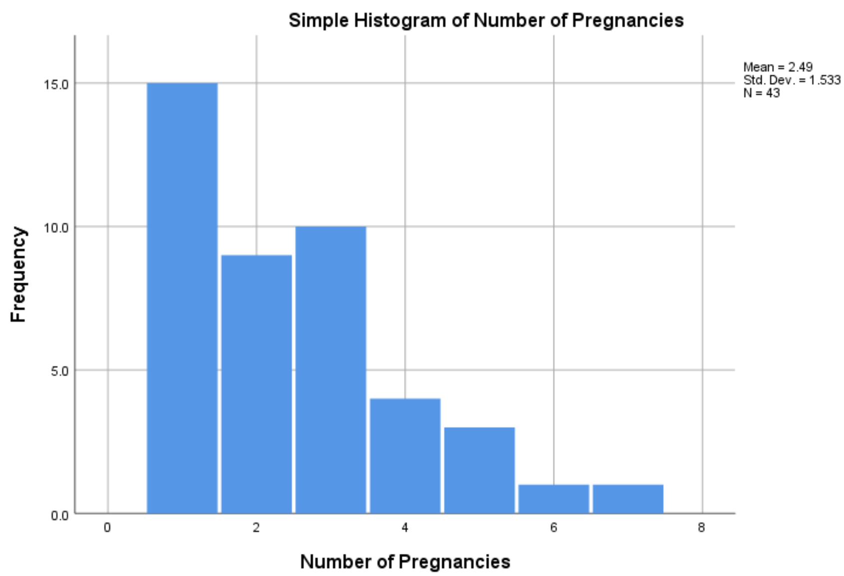
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	20	45.5	48.8	48.8
	Female	21	47.7	51.2	100.0
	Total	41	93.2	100.0	
Missing	System	3	6.8		
Total		44	100.0		


Simple Histogram of Child's Age in Days
Mean = 315.02
Std. Dev. = 178.749
N = 42
Frequency
10.0
8.0
6.0
4.0
2.0
0.0
0
200
400
600
800
Child's Age in Days


Simple Histogram of Mother's Age in Years
Mean = 24.43
Std. Dev. = 4.957
N = 14
Frequency
4.0
3.0
2.0
1.0
0.0
15
20
25
30
35
40
Mother's Age in Years


Simple Histogram of Age Married
Mean = 18.76
Std. Dev. = 3.491
N = 42
Frequency
10.0
8.0
6.0
4.0
2.0
0.0
10
15
20
25
30
Age Married


Simple Histogram of Age Pregnant
Mean = 18.37
Std. Dev. = 3.331
N = 43
Frequency
Age Pregnant


Simple Histogram of Number of Pregnancies
Mean = 2.49
Std. Dev. = 1.533
N = 43
Frequency
Number of Pregnancies

Appendix F: T-Test Results

	Standard Deviation & Geometric Mean Among Households with stored water (95% CI)	Standard Deviation & Geometric Mean Among Households without stored water (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	1.1131; 0.9530 (0.5922,1.3139)	0.8153; 0.3398 (-0.6726,1.3522)	Pooled: -1.19	42	0.2422
Child's drinking water EC	0.2090; 0.8653 (0.4391,1.2916)	0.4980; 0.4593 (-0.9233,1.8420)	Pooled: -0.72	35	0.4771
Mother's Hand Rinse EC	0.8685; 0.7240 (0.4425,1.0056)	1.0649; 0.6743 (-0.6480,1.9965)	Pooled: -0.12	42	0.9068
Child's hand rinse EC	0.8115; 0.3315 (0.0647,0.5982)	0.3925; -0.0602 (-0.5476,0.4271)	Pooled: -1.05	41	0.2977
Ball sentinel toy EC	0.6623; -0.0211 (-0.2420,0.1997)	0; -0.3010 (-0.3010, -0.3010)	Satterth.: -2.57	36	0.0144*
Duck sentinel toy EC	0.9226; 0.3792 (-0.1783, 0.9367)	0.8876; 0.3266 (-7.6483,8.3015)	Pooled: -0.08	13	0.9411
Food prep location EC	1.0358; 0.6232 (0.2874,0.9590)	0.7625;0.2742(-0.9390,1.4875)	Pooled: -0.65	41	0.5176
Child's eating location EC	0.8076; 0.1943 (-0.1252, 0.5137)	-, -0.3010 (-,-)	Pooled: -0.60	26	0.5522

Compared $\log_{10}$ Environmental EC results in Housholds with and without stored water. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with animals (95% CI)	Standard Deviation & Geometric Mean Among Households without animals (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	0.7954; 0.5254(0.0849,0.9658)	1.1897; 1.0685(0.6160,1.5211)	Pooled: 1.59	42	0.1195
Child's drinking water EC	0.9831; 0.5684(-0.0563,1.1930)	1.2472; 0.9267(0.4119,1.4415)	Pooled: 0.87	35	0.3894
Mother's Hand Rinse EC	0.7587; 0.8100(0.3898,1.2301)	0.9442;0.6710(0.3119,1.0302)	Pooled: -0.49	42	0.6248
Child's hand rinse EC	0.7725; 0.3910(-0.0819,0.8639)	0.6131;0.2352(-0.0586,0.5291)	Pooled: -0.61	41	0.5467
Ball sentinel toy EC	0.9167; -0.00083(-0.5548.0.5532)	0.4693; -0.0706 (-0.2525,0.1114)	Satterth.: -0.26	14.99	0.7992
Duck sentinel toy EC	0.4904; 0.0352(-0.5736,0.6441)	1.0107;0.5407(-0.1823,1.2637)	Pooled: 1.04	13	0.3155
Food prep location EC	0.9421; 0.6122(0.0905,1.1339)	1.0632; 0.5792(0.1669,0.9915)	Pooled: -0.10	41	0.9201
Child's eating location EC	0.3740; -0.0733(-0.3608,0.2141)	0.9203;0.2949(-0.1486,0.7385)	Satterth.: 1.50	25.71	0.1453

Compared $\log_{10}$ Environmental EC results in Housholds with and without animals. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with washing station (95% CI)	Standard Deviation & Geometric Mean Among Households without washing station (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	0.7995; 0.3809(-0.0807,0.8425)	1.1406;1.0212(0.5700,1.4724)	Pooled: 1.87	39	0.0689
Child's drinking water EC	0.6460; 0.0428(-0.3912,0.4767)	1.1686;1.1225(0.6172,1.6279)	Pooled: 2.85	32	0.0076*
Mother's Hand Rinse EC	0.5549; 0.4762(0.0343,0.9181)	0.9508;0.8219(0.4457,1.1980)	Pooled: 1.17	39	0.2471
Child's hand rinse EC	0.6998; 0.1460 (-0.2581,0.5501)	0.8021; 0.3502 (0.0262,0.6742)	Pooled: 0.80	38	0.4280
Ball sentinel toy EC	0.1670; -0.2547(-0.3556,-0.1538)	0.4928; -0.0549(-0.2584,0.1485)	Satterth.: 1.83	32.59	0.0757
Duck sentinel toy EC	0.4257; -222E-19(-0.5286,0.5286)	0.7192; 0.5143 (-0.3041,1.3327)	Pooled: 1.02	12	0.3276
Food prep location EC	0.8928; 0.4302(-0.0853,0.9457)	0.7808;0.5636(0.1615,0.9657)	Pooled: 0.42	38	0.6779
Child's eating location EC	0.4503; -0.0860(-0.5025,0.3305)	0.4737;0.112(-0.2027,0.4251)	Pooled: 0.75	23	0.4601

Compared $\log_{10}$ Environmental EC results in Households with and without a washing station. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with water sink (95% CI)	Standard Deviation & Geometric Mean Among Households without water in sink (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	0.7641; 0.6502(0.2350,1.0653)	1.9056; 1.3493 (-1.6830,4.3815)	Scatterth.: 0.72	3.27	0.5207
Child's drinking water EC	1.1798; 0.6230(0.0708,1.1752)	0.8505; 0.5247 (-1.5880,2.6374)	Pooled: -0.14	21	0.8917
Mother's Hand Rinse EC	0.7962; 0.6987(0.3624,1.0349)	0.2882; -0.0753(-0.5339,0.3834)	Pooled: -1.90	26	0.0689
Child's hand rinse EC	0.8124;0.2895(-0.0536,0.6325)	0.6901; 0.0440(-1.0541,1.1421)	Pooled: -0.57	26	0.5745
Ball sentinel toy EC	0.4284; -0.1469(-0.3368,0.0431)	0.1505; -0.2258(-0.4653,0.0137)	Pooled: -0.36	24	0.7227
Duck sentinel toy EC	0.9111; 0.4758(-0.0748,1.0263)	0; -0.3010(-0.3010, -0.3010)	Scatterth.: -3.07	12	0.0096*
Food prep location EC	0.8022;0.5278(0.1891,0.8666)	0..6882; 0.1360(-0.9591,1.2311)	Pooled: -0.92	26	0.3669
Child's eating location EC	0.3191;-0.1605(-0.3373,0.0162)	0; -0.3010(-0.3010, -0.3010)	Scatterth.: -1.70	14	0.1103

Compared $\log_{10}$ Environmental EC results in Households with and without available water. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with soap in sink (95% CI)	Standard Deviation & Geometric Mean Among Households without soap in sink (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	0.9949; 0.7229(0.2818,1.1641)	1.6696; 0.8493(-0.9028,2.6015)	Pooled: 0.24	26	0.8142
Child's drinking water EC	1.1971; 0.6127(0.0174,1.2080)	0.9431; 0.6011(-0.5699,1.7721)	Pooled: -0.02	21	0.9843
Mother's Hand Rinse EC	0.8001; 0.7285(0.3738,1.0833)	0.5319; 0.0732(-0.4850,0.6315)	Pooled: -1.88	26	0.0711
Child's hand rinse EC	0.8260; 0.2840(-0.0822,0.6502)	0.6927;0.1458(-0.5811,0.8728)	Pooled: -0.37	26	0.7114
Ball sentinel toy EC	0.2831; -0.2136(-0.3461.-0.0811)	0.6575; 0.0231(-0.669,0.7130)	Satterth.: 0.86	5.57	0.42622
Duck sentinel toy EC	0.9447; 0.3774(-0.2573,1.0121)	0.8327; 0.3578(-0.9672,1.6829)	Pooled: -0.04	13	0.9715
Food prep location EC	0.8264; 0.5324(0.1660,0.8988)	0.6374; 0.2497(-0.4192,0.9186)	Pooled: -0.77	26	0.4462
Child's eating location EC	0.3287; -0.1505(-0.3403,0.0393)	0; -0.3010(-0.3010,-0.3010)	Satterth,: -1.71	13	0.1104

Compared $\log_{10}$ Environmental EC results in Households with and without available soap. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with improved water source (95% CI)	Standard Deviation & Geometric Mean Among Households with unimproved water source (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	0.9926; 0.8290(0.4441,1.2139)	1.2800; 0.9785(0.2965,1.6606)	Pooled: -0.43	42	0.6678
Child's drinking water EC	1.0769; 0.6829(0.2055,1.1604)	1.3030; 0.9975(0.2759,1.7190)	Pooled: -0.80	35	0.4285
Mother's Hand Rinse EC	0.9578; 0.8133(0.4419, 1.1847)	0.7188; 0.5523(0.1692,0.9353)	Pooled: 0.95	42	0.3492
Child's hand rinse EC	0.6614; 0.1888(-0.0728,0.4504)	0.9524; 0.4498(-0.0577,0.9573)	Pooled: -1.06	41	0.2954
Ball sentinel toy EC	0.7107; -0.0332(-0.3203,0.2539)	0.4949; -0.0749(-0.3490,0.1991)	Pooled: 0.20	39	0.8420
Duck sentinel toy EC	1.2461; 0.3920(-0.9157,1.6997)	0.6363; 0.3590(-0.1301,0.8481)	Pooled: 0.07	13	0.9467
Food prep location EC	0.8590; 0.5179(0.0864,0.9494)	0.8808; 0.7137(0.2443,1.1830)	Pooled: -0.61	41	0.5459
Child's eating location EC	0.6605; 0.2737(-0.0658,0.6133)	0.9902; 0.0264(-0.6388,0.6916)	Pooled: 0.80	26	0.4335

Compared $\log_{10}$ Environmental EC results in Households with and without improved water source. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with improved drinking water source (95% CI)	Standard Deviation & Geometric Mean Among Households with unimproved drinking water source (95% CI)	T-test for difference (comparison of log_{10} transformation)	DF	P-value
Source water EC	0.9839; 0.8309(0.4635,1.1983)	1.3321; 0.9957(0.2266,1.7649)	Pooled: -0.46	42	0.6469
Child's drinking water EC	0.8296; 0.6811(0.2304,1.1319)	1.3434; 1.0492(0.2374,1.8610)	Pooled: -0.91	35	0.3669
Mother's Hand Rinse EC	0.9300; 0.8038(0.4566,1.1511)	0.7567; 0.5353(0.0984, 0.9722)	Pooled: 0.94	42	0.3511
Child's hand rinse EC	0.6558; 0.1946(-0.0549,04440)	0.9952; 0.4752(-0.0994,1.0498)	Pooled: -1.11	41	0.2751
Ball sentinel toy EC	0.6875; -0.0523(-0.3189,0.2143)	0.5253; -0.0401(-0.3576,0.2773)	Pooled: -0.06	39	0.9552
Duck sentinel toy EC	1.1403; 0.4220(-0.6326,1.4766)	0.6732; 0.3286(-0.2342,0.8914)	Pooled: 0.20	13	0.8472
Food prep location EC	1.0622; 0.5575(0.1535,0.9615)	0.9311; 0.6596(0.1220,1.1972)	Pooled: -0.31	41	0.7606
Child's eating location EC	0.6549; 0.2418(-0.0839,0.5675)	1.0375; 0.0591(-0.6830,0.8013)	Pooled: 0.57	26	0.5715

Compared log_{10} Environmental EC results in Households with and without improved drinking water source. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with treated water (95% CI)	Standard Deviation & Geometric Mean Among Households without treated water (95% CI)	T-test for difference (comparison of log_{10} transformation)	DF	P-value
Source water EC	1.0708; 0.9289(0.4768,1.3811)	1.1453; 0.8287(0.2927,1.3646)	Pooled: 0.30	42	0.7658
Child's drinking water EC	1.1741; 0.7117(0.1621,1.2612)	1.1829; 0.9267(0.3185,1.5349)	Pooled: -0.55	35	0.5836
Mother's Hand Rinse EC	0.9273; 0.7113(0.3198,1.1029)	0.8408; 0.7268(0.3333,1.1203)	Pooled: -0.06	42	0.9544
Child's hand rinse EC	0.5901; 0.1811(-0.0741,0.4363)	0.9585; 0.4065(-0.0421,0.8551)	Satterth.: -0.91	30.71	0.3688
Ball sentinel toy EC	0.4224; -0.1098(-0.2971,0.0775)	0.8216; 0.0226(-0.3734,0.4185)	Satterth.: -0.63	26	0.5319
Duck sentinel toy EC	0.5724; 0.3794(-0.2213,0.9801)	1.0821; 0.3674(-0.4644,1.1992)	Pooled: 0.02	13	0.9806
Food prep location EC	0.9465; 0.4305(0.02130.8398)	1.0756; 0.7749(0.2715,1.2783)	Pooled: -1.12	41	0.2705
Child's eating location EC	0.5682; -0.00452(-0.2967,0.2876)	1.0300; 0.4564(-0.2355,1.1484)	Satterth.: -1.36	13.99	0.1964

Compared log_{10} Environmental EC results in Households with and without treated water. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with improved child's drinking water (95% CI)	Standard Deviation & Geometric Mean Among Households with unimproved child's drinking water (95% CI)	T-test for difference (comparison of log_{10} transformation)	DF	P-value
Source water EC	0.9882; 0.7566(0.4003,1.1129)	2.0618; 1.2214(0.3809,2.0618)	Pooled: -1.26	42	0.2131
Child's drinking water EC	1.0376; 0.5615(0.1424,0.9806)	1.2910; 1.3989(0.5316,2.2662)	Pooled: -2.09	35	0.0443*
Mother's Hand Rinse EC	0.9112; 0.7724(0.4439,1.1009)	0.8053; 0.5743(0.0626,1.0860)	Pooled: 0.66	42	0.5118
Child's hand rinse EC	0.6551; 0.1701(-0.702,0.4104)	1.0135; 0.5851(-0.0589,1.2290)	Pooled: -1.59	41	0.1196
Ball sentinel toy EC	0.6650; -0.0589(-0.3072,0.1895)	0.5689; -0.0201(-0.4023,0.3621)	Pooled: -0.17	39	0.8647
Duck sentinel toy EC	1.0371; 0.4008(-0.3963,1.1980)	0.6906; 0.3292(-0.3955,1.0540)	Pooled: 0.15	13	0.8848
Food prep location EC	1.0371; 0.4721(0.0917,0.8525)	0.9109; 0.8971(0.3184,1.4758)	Pooled: -1.24	41	0.2206
Child's eating location EC	0.6549; 0.2418(-0.0839,0.5675)	1.0375; 0.0591(-0.6830,0.8013)	Pooled: 0.57	26	0.5715

Compared log_{10} Environmental EC results in Households with and without improved child's drinking water source. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with child's drinking water treatment (95% CI)	Standard Deviation & Geometric Mean Among Households without child's drinking water treatment (95% CI)	T-test for difference (comparison of log_{10} transformation)	DF	P-value
Source water EC	1.2970; 0.9759(0.2576,1.6941)	0.9939; 0.8355(0.4575,1.2136)	Pooled: 0.40	42	0.6915
Child's drinking water EC	1.2022; 0.9658(0.2393,1.6922)	1.1643;0.7263(0.2347,1.2180)	Pooled: 0.59	35	0.5586
Mother's Hand Rinse EC	1.0141; 0.07811(0.2195,1.3427)	0.8178; 0.6859(0.3749,0.9970	Pooled: 0.34	42	0.7378
Child's hand rinse EC	0.6675; 0.2126(-0.1570,0.5823)	0.8455; 0.3252(-0.00265,0.6530)	Pooled: -0.45	41	0.6581
Ball sentinel toy EC	0.4559; -0.1283(-0.4038,0.1472)	0.7060; -0.0114(-0.2851,0.2624)	Pooled: -0.54	39	0.5891
Duck sentinel toy EC	0.7567; 0.5964(-0.6077,1.8005)	0.9495; 0.2907(-0.3472,0.9285)	Pooled: 0.5743	13	0.5743
Food prep location EC	1.2442; 0.7194(0.000998,1.4378)	0.8962; 0.5286(0.1877,0.8695)	Pooled: 0.58	41	0.5684
Child's eating location EC	1.1345; 0.4252(-0.3864,1.2368)	0.5229; 0.0385(-0.2216,0.2985)	Satterth.: 1.02	11.17	0.3296

Compared log_{10} Environmental EC results in Households with and without child's drinking water treatment. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households with agricultural land (95% CI)	Standard Deviation & Geometric Mean Among Households without agricultural land (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	0; -0.3010(-0.3010,-0.3010)	1.0176; 0.8125(0.4913,1.1337)	Satterth.: 7.01	40	<0.0001*
Child's drinking water EC	0; -0.3010(-0.3010,-0.3010)	1.0902; 0.7237(0.3434,1.1041)	Satterth. 5.48	33	<0.0001*
Mother's Hand Rinse EC	0.7993; 0.8662(-6.3149,8.0473)	0.9028; 0.7024(0.4174,0.9873)	Pooled: -0.25	41	0.8029
Child's hand rinse EC	0.2129; -0.1505(-2.0630,1.7620)	0.7997; 0.3149(0.0592,0.5706)	Pooled: 0.81	40	0.4212
Ball sentinel toy EC	.; -0.3010	0.6563; -0.364(-0.2522,0.1793)	Pooled: 0.40	37	0.6930
Duck sentinel toy EC	.;2.7782	0.06079; 0.2003(-0.1507,0.5514)	Pooled: -4.10	13	0.0013*
Food prep location EC	0; 0(0,0)	0.9696; 0.5525(0.2424,0.8626)	Satterth.: 3.60	39	0.0009*
Child's eating location EC	.;0	0.5928; 0.0864(-0.1531,0.3258)	Pooled: 0.14	25	0.8875

Compared log10 Environmental EC results in Households with and without agricultural land. *Statistically significant results.

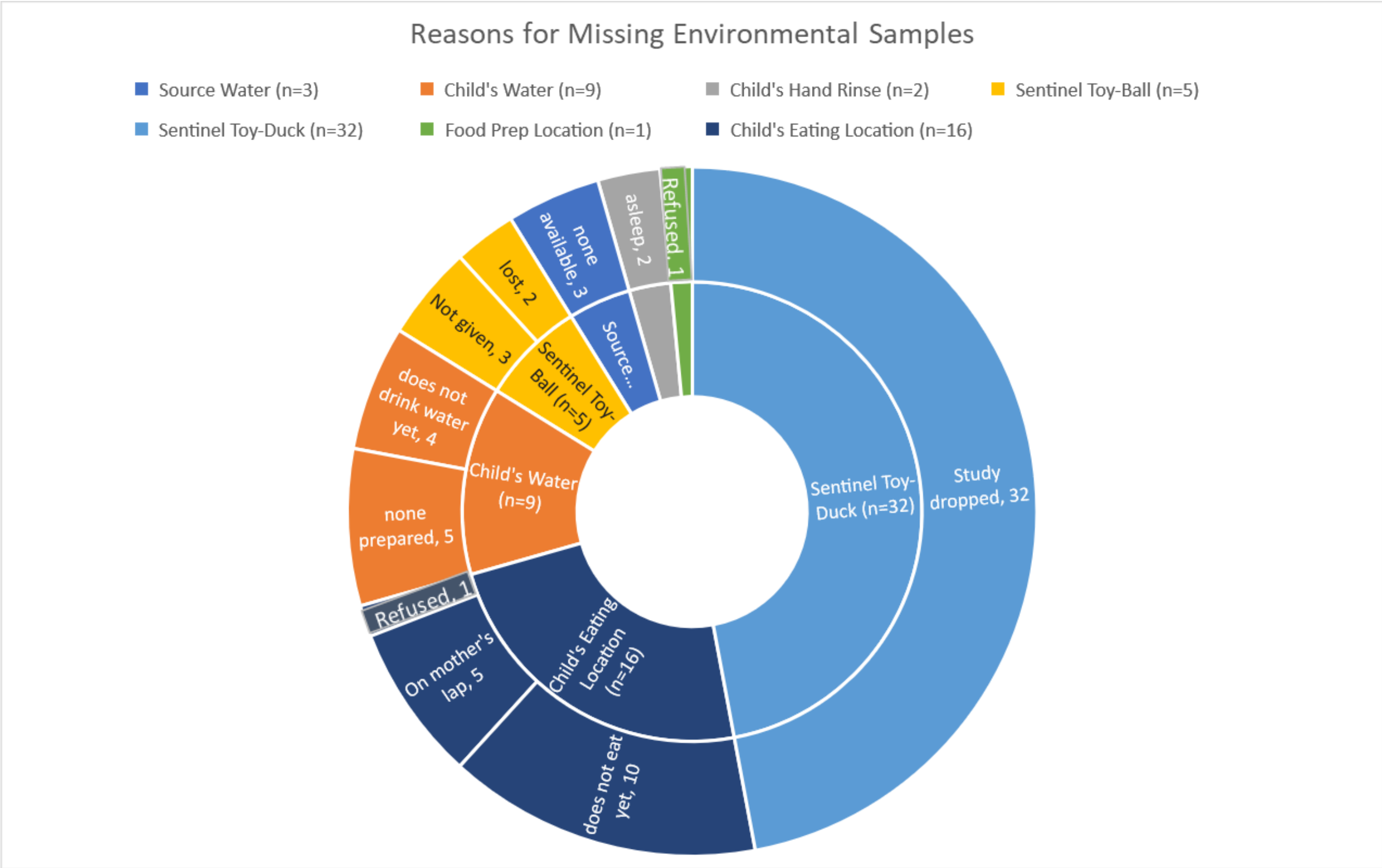
	Standard Deviation & Geometric Mean Among Households with a bank account (95% CI)	Standard Deviation & Geometric Mean Among Households without a bank account (95% CI)	T-test for difference (comparison of $\log_{10}$ transformation)	DF	P-value
Source water EC	1.1312; 0.8904(0.3088,1.4720)	0.9558; 0.6759(0.2899,1.0620)	Pooled: -0.67	41	0.5073
Child's drinking water EC	0.8873; 0.3776(-0.1347,0.8899)	1.1762; 0.8509(0.3294,1.3724)	Pooled: 1.29	34	0.2065
Mother's Hand Rinse EC	0.7120; 0.4768(0.1108,0.8429)	0.9727; 0.8624(0.4696,1.2553)	Pooled: 1.40	41	0.1677
Child's hand rinse EC	0.9899; 0.3715(-0.1375,0.8804)	0.6306; 0.2392(-0.0211,0.4995)	Satterth.: -0.49	24.79	0.6300
Ball sentinel toy EC	0.8273; -0.00067(-0.4415,0.4402)	0.5086; -0.0728(-0.2928,0.1471)	Satterth.: -0.31	22.85	0.7591
Duck sentinel toy EC	0.4573; 0.1799(-0.3001,0.6598)	1.0949; 0.5004(-0.3412,1.3421)	Pooled: 0.67	13	0.5131
Food prep location EC	0.6828; 0.3738(0.0227,0.7248)	1.1016; 0.6299(0.1751,1.0846)	Pooled: 0.85	40	0.3994
Child's eating location EC	0.4541; -0.0801(-0.3686,0.2084)	0.6518; 0.2138(-0.1472,0.5747)	Pooled:1.32	25	0.1977

Compared $\log_{10}$ Environmental EC results in Households with and without a bank account. *Statistically significant results.

	Standard Deviation & Geometric Mean Among Households who own their home (95% CI)	Standard Deviation & Geometric Mean Among Households who don't own their home (95% CI)	T-test for difference (comparison of log_{10} transformation)	DF	P-value
Source water EC	0.9434; 0.7884(0.3900,1.1867)	1.1371; 0.7257(0.1777,1.2738)	Pooled: -0.20	41	0.8444
Child's drinking water EC	1.1936; 0.7269(0.1333,1.3204)	0.9958; 0.6067(0.1115,1.1019)	Pooled: -0.33	34	0.7449
Mother's Hand Rinse EC	0.9295; 0.7729(0.3804,1.1654)	0.8566; 0.6305(0.2177,1.0434)	Pooled: -0.52	41	0.6086
Child's hand rinse EC	0.6197; 0.1454(-0.1162,0.4071)	0.9502; 0.4891(0.0166,0.9617)	Pooled: 1.42	40	0.1640
Ball sentinel toy EC	0.2739; -0.2079(-0.3293,-0.0864)	0.9036; 0.1699(-0.2947,0.6344)	Satterth.: 1.67	18.28	0.1128
Duck sentinel toy EC	1.1309; 0.7629(-0.4239,1.9497)	0.6211; 0.1117(-0.3657,0.5891)	Pooled: -1.45	13	0.1716
Food prep location EC	0.9496; 0.5891(0.1785,0.9997)	0.9777; 0.4501(-0.0212,0.9213)	Pooled: -0.47	40	0.6437
Child's eating location EC	0.7000; 0.1474(-0.2756,0.5704)	0.4649; 0.0235(-0.2449,0.2919)	Pooled: -0.55	25	0.5901

Compared log_{10} Environmental EC results in Households with and without home ownership. *Statistically significant results.

Appendix G


Reasons for Missing Environmental Samples
Source Water (n=3)
Child's Water (n=9)
Child's Hand Rinse (n=2)
Sentinel Toy-Ball (n=5)
Sentinel Toy-Duck (n=32)
Food Prep Location (n=1)
Child's Eating Location (n=16)
Sentinel Toy-Duck (n=32)
Study dropped, 32
Child's Eating Location (n=16)
does not eat yet, 10
On mother's lap, 5
Refused, 1
Child's Water (n=9)
none prepared, 5
does not drink water yet, 4
Sentinel Toy-Ball (n=5)
Not given, 3
lost, 2
Source...
none available, 3
asleep, 2
Refused, 1

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