Research Paper

An evaluation of water, sanitation, and hygiene status and household assets and their associations with soil-transmitted helminthiasis and reported diarrhea in Nueva Santa Rosa, Guatemala

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ABSTRACT

Soil-transmitted helminth (STH) infections and diarrheal illness affect billions of people yearly. We conducted a cross-sectional survey in Nueva Santa Rosa, Guatemala to identify factors associated with STH infections and diarrhea using univariable and multivariable logistic regression models. On multivariable analyses, we found associations between STH infections and two factors: school-aged children (odds ratio (OR) vs. adults: 2.35, 95% CI 1.10–4.99) and household drinking water supply classified as 'other improved' (OR vs. 'improved': 7.00, CI 1.22–40.14). Finished floors in the household vs. natural floors were highly protective (OR 0.16, CI 0.05–0.50) for STH infection. In crowded households (>2.5 people/bedroom), observing water present at handwashing stations was also protective (OR 0.32, CI 0.11–0.98). When adjusted for drying hands, diarrhea was associated with preschool-age children (OR vs. adults: 3.33, CI 1.83–6.04), spending >10 min per round trip collecting water (OR 1.90, CI 1.02–3.56), and having a handwashing station ≤10 m near a sanitation facility (OR 3.69, CI 1.33–10.21). Our study indicates that familiar WASH interventions, such as increasing drinking water quantity and water at handwashing stations in crowded homes, coupled with a hygiene intervention like finished flooring may hold promise for STH and diarrhea control programs.

Key words | diarrhea, Guatemala, hygiene, sanitation, soil-transmitted helminths, water

HIGHLIGHTS

- School-aged children had over 2× the odds of STH infection than adults in our study.
- 'Other improved' water as household drinking water was associated with 7× the odds of developing STH infection compared with 'improved' water.
- Households with finished floors were protective for STH infection compared with natural floors.
- Improved WASH interventions need consideration for STH and diarrheal disease control programs.

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INTRODUCTION

The World Health Organization (WHO) estimates that 1.5 billion people are afflicted with soil-transmitted helminth (STH) infections (WHO 2017b, 2019). STH infections are a category of parasites that commonly include roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*), and hookworm (*Necator americanus* and *Ancylostoma duodenale*). In 2010, an estimated 5.3 billion people worldwide lived in areas with stable transmission of at least one STH species (Pullan & Brooker 2012). STH infections are treated with anthelminthic drugs, which are commonly distributed in mass drug administration (MDA) campaigns to preschool-aged children (PSAC) and school-aged children (SAC). In addition to anthelminthic treatment, recent studies also demonstrate the combination of safe drinking water, appropriate sanitation facilities, and good hygiene practices (WASH) along with STH programs (i.e., MDA campaigns) reduce STH reinfection (Strunz *et al.* 2014).

The WHO estimates 1.7 billion cases of childhood diarrhea occur globally each year and that diarrhea is the fifth leading cause of death among children younger than 5 years of age (GBD Diarrhoeal Diseases Collaborators 2017; WHO 2017b). Among children, recurrent episodes of diarrhea can result in long-term effects including impaired cognitive development, impaired school performance, and growth faltering (Lorntz *et al.* 2006; Troeger *et al.* 2018). Many studies have suggested that diarrhea might be reduced through various WASH interventions that interrupt the fecal-oral route of transmission (Luby *et al.* 2004, 2018; Opryszko *et al.* 2010). Other studies have found mixed or little effect of WASH interventions on diarrhea incidence (Null *et al.* 2018; Reese *et al.* 2019; Rogawski McQuade *et al.* 2019).

Additional evidence is needed to better understand the factors for STH infection and diarrhea and to help guide programmatic decision making focused on the integration of WASH interventions. The aim of this study was to explore the WASH and demographic factors associated with diarrhea and STH infections, in communities of southeastern Guatemala. We conducted a cross-sectional survey in 2010 to collect information about household WASH condition, knowledge, attitudes, practices related to WASH, demographics, animal ownership, and examined associations with laboratory-confirmed STH infections and self-reported diarrhea.

MATERIALS AND METHODS

Study design and sampling methods

In 2010, we conducted a cross-sectional survey in Nueva Santa Rosa (NSR) municipio (county), southeast of Guatemala City, Guatemala to determine multiple outcomes, including the population prevalence/incidence of and health-seeking behaviors for soil-transmitted helminthiasis (STH), diarrhea, and influenza-like illness (ILI). A secondary objective of this study was to complete a pilot study to assess the status of WASH in NSR and to evaluate the impact WASH status had on these diseases. The study included PSAC, SAC, women of childbearing age (WCBA), and other adults. Children <1 year of age were not included in the STH analyses due to lack of WHO deworming dosage recommendations for this age group (Montresor *et al.* 2003; WHO 2017a). The household sampling frame was determined using aerial photos overlaid by 200 m × 200 m grid cells. The potential residential-associated (PRA) roofs were identified and geolocated ($n =$ 10,770), and a subset of PRA roofs was randomly selected ($n = 387$). Sample size calculations were performed using Cochran's formula (Cochran 1977), and sample sizes were calculated for each of the multiple primary outcomes, of which health-seeking behavior for ILI required the largest sample size of 387 PRA roofs (Matanock *et al.* 2018). This sample size was insufficient for the WASH component of this study, which was underpowered 2–3 fold but was a pilot test of the survey instruments for future investigations. Resources were unavailable to increase the size of the study to fully power the WASH pilot at that time. The sample size was converted using modifiers from the number of individuals needed to the number of PRA roofs needed. These modifiers included design effect, estimated number of persons per household, nonresponse rate, estimated percentage of non-residential roofs in the sample, estimated percentage of roofs that would not be found in the field, and estimated proportion of roofs in the sample that would belong to households already surveyed. PRA roof is not an exact proxy for household because, in this area of Guatemala, dwellings are constructed such that rooms serving different functions are often constructed in separate buildings with separate roofs. Therefore, a single household may have multiple PRA roofs. For example, depending upon the socioeconomic status (SES) and location of an individual or family, a single household may have several buildings (e.g., kitchen, sleeping quarters, and main building). Study staff identified each randomly selected PRA roof in the field with the aid of maps made from the aerial photos and GPS coordinates, and then identified the household associated with each roof, if applicable, to try to recruit the occupants and administer the questionnaire. Further details on the sampling frame design can be found in Matanock *et al.* (2018).

Consent and data collection

A cross-sectional household survey and observational environment assessment were conducted to evaluate demographic data, WASH infrastructure and conditions, health status, and health-seeking behaviors of household members. Written consent for study participation was sought from each household member present at the time of interview: adult consent, parental consent, and assent from children aged 7–17 years (see Supplementary Material, Appendix 1–3). The consent form included permission to ask questions about household members both present and not present at the time of interview and permission to collect and test stool specimens and water samples. Then, an adult household spokesperson was identified to complete the questionnaires. In order of preference, this spokesperson was (1) the adult female head of household, (2) the eldest teenage daughter in the presence of an adult household member, (3) the adult male head of household, and (4) any consenting adult for the household. This order of preference reflected the likely level of knowledge about the household WASH status. All persons present during the interview were informed that the spokesperson would be asked the questions but if they wish to refuse disclosing or provide information they could. At the conclusion of the interview, the household spokesperson was given one stool collection kit for every person in the household $\geq$1 year of age for STH (Montresor *et al.* 2003; WHO 2017a). Household members who were not present at the time of the interview were asked to include their signed consent form with their stool specimens. Stool specimens provided without signed consent forms were not accepted. Diarrhea was self-reported and defined as loose stool in the past 7 days.

Stool specimens were tested using the Mini Parasep® Fecal Parasite Concentrator (FPC) method (Apacor, Berkshire, UK). Individuals who tested positive for one or more of *Ascaris* sp., *Trichuris* sp., or hookworm were considered to be STH-infected. For the environmental assessment, the household spokesperson was asked to show the interviewer the main handwashing place for the household and to demonstrate how she/he washed her/his hands. Additionally, a member of the family took a field staff member to observe and evaluate the toilet or latrine used most often by household members and observed where the family collects their drinking water. During the interview and the environmental assessment, the condition of the house, yard, and household surroundings was also observed using a standardized observational worksheet. A modified definition of the WHO/JMP Water Ladder was used for all analyses comparing 'improved' water (piped household water connection located inside the dwelling, yard, or plot); 'other improved' (public tap, borehole, protected dug well, protected spring, rainwater collection), bottled water; and 'unimproved' water sources (unprotected dug well, unprotected spring, water cart, tanker truck, surface water) (WHO 2010).

Data management and statistical analysis

Logistic regression models were used to assess the association between the candidate factors and two outcomes: STH and diarrhea. The STH outcome was positive if any of the FPC tests for *Ascaris*, *Trichuris*, or hookworm were positive. Models for STH excluded participants under 1 year of age. A factor analysis on the subset of variables with more than five affirmative responses resulted in two SES factors being identified – one primarily dependent on household possessions ('household characteristics factor') and the other on animal ownership ('animal ownership factor'). Resulting SES factor scores were dichotomized at zero and evaluated as potential risk factors. Further details are available (Matanock *et al.* 2018).

Univariable logistic models of the association between WASH and demographic factors and STH infection were constructed using survey methods to take household clustering and weight by the inverse number of roofs per household. The variable 'age/sex' combined PSAC, SAC, WCBA, and other adults with distinct age groups (1–4 years old, 5–14 years old, 15–44 years old, and >15 years old, respectively). These specific age/sex categories were defined based on at-risk population groups for STH infections and commonly used across deworming programs (WHO 2018). The age group category for self-reported diarrhea did not differentiate between WCBA and other adults.

Variables initially considered for the multivariable models were identified from a subset of WASH factors chosen *a priori*, taking into consideration missingness (excluded variables with <5 observations in category) and correlations between variables (variable chosen from the correlated group based on subject matter expertise). Candidate multivariable models were determined using group LASSO. Main effect models were selected from candidate models using cross-validation error, subject matter knowledge, and maximum degrees of freedom, determined by the number of people in the sample who experienced each outcome. LASSO was used once more to determine whether relevant two-way interactions involving main effects should be included in the model. After using LASSO for model selection, multivariable parameter estimates were obtained using logistic regression accounting for survey weights. Additional details can be found in Supplementary Material, Methods: Data Collection & Statistical Analysis.

Human subjects protection

This study was conducted in accordance with the ethical standards of the Helsinki Declaration of the World Medical Association (WMA 2001). The protocol was approved by the Ethics Committee of the Universidad del Valle de Guatemala (UVG) in Guatemala City, Guatemala (protocol 038-04-2010, approval date 19 July 2010) and the Institutional Review Board of the Centers for Disease Control and Prevention (CDC) in Atlanta, GA, USA (protocol 5936, approval date 18 June 2010). Written informed consent was obtained from persons 18 and older; written parental consent was obtained for children <18 years old and children 7–17 years provided written assent to participate. Persons testing positive for STH were provided treatment according to the national treatment guidelines free of charge through the Guatemala Ministry of Public Health and Social Welfare using drugs purchased for this study.

RESULTS

This study had a total of 920 participants. Of the 915 participants with gender reported, 495 (54%) were female, and 420 (46%) were male. Of the 906 participants ≥1 year of age, 701 (77%) respondents provided a stool sample for testing. The mean ages in years of the age groups providing stool samples were 2.26 (PSAC), 9.8 (SAC), 27.6 (WCBA), and 45.4 for other adults. Of the 701 stool samples, 65 (9%) tested positive for STH infections, and 636 (91%) tested negative for STH infections. The majority of STH positive infections ($n = 59$, 91%) were *Ascaris* infections only, followed by two (3%) *Trichuris* only, and one (1.5%) hookworm only infections. Two individuals had co-infections, one with *Ascaris* and hookworm (1.5%) and one with *Ascaris* and *Trichuris* (1.5%). Overall, 81 (9%) household participants self-reported diarrhea, and 821 (89%) and 18 (2%) either reported not having diarrhea or gave no response (i.e., missing), respectively. The overall demographic results for the STH and diarrhea study components are found in Table 1.

Table 2 demonstrates the univariable and multivariable model results, for STH and diarrhea analyses. For the STH outcome, univariable results show that having more household possessions vs. less (OR 0.11, CI 0.04–0.34) and finished floors vs. natural floors were highly protective (OR 0.18, CI 0.08–0.41). Observed drinking water supplies of 'other improved' or 'unimproved' water quality status (OR 5.57, CI 1.90–16.36; OR 6.09, CI 1.52–24.37) were also associated with higher odds of STH infection compared with observed water supplies of 'improved' water quality status. The unadjusted univariable analysis indicated the odds of having an STH infection were higher for SAC than adults (OR 2.38, CI 1.22–4.65) and higher for crowded

Table 1 | Demographics of surveyed households by health status assessment type in NSR, Guatemala – 2010

	Diarrhea				STH			
Variable	N[a]	Diarrhea status reported[b], n (%)	Diarrhea Yes, n (%)	Diarrhea No, n (%)	$N \geq 1$ year old[c]	Provided stool, n (%)	STH positive, n (%)	STH negative, n (%)
Overall	920	902 (98)	81 (9)	821 (91)	906	701 (77)	65 (9)	636 (91)
Age group*								
Preschool-age children	97	94 (97)	17 (18)	77 (82)				
School-age children	250	249 (100)	21 (8)	228 (92)				
Adults	566	558 (99)	43 (8)	515 (92)				
Age/sex†								
Preschool-age children					83	76 (92)	7 (9)	69 (91)
School-age children					250	202 (81)	30 (15)	172 (85)
WCBA					210	167 (80)	11 (7)	156 (93)
Other adults					356	256 (72)	17 (7)	239 (93)
Gender								
Male	420	410 (98)	34 (8)	376 (92)	410	307 (75)	31 (10)	276 (90)
Female	495	492 (99)	47 (10)	445 (90)	489	394 (81)	34 (9)	360 (91)
Ethnicity								
Ladino	803	788 (98)	64 (8)	724 (92)	785	617 (79)	51 (8)	566 (92)
Indigenous	22	21 (95)	3 (14)	18 (86)	22	12 (55)	1 (8)	11 (92)
Xinca	74	73 (99)	10 (14)	63 (86)	71	53 (75)	13 (25)	40 (75)
Education								
Did not attend school	164	161 (98)	17 (11)	144 (89)	162	126 (78)	14 (11)	112 (89)
Primary incomplete	497	488 (98)	42 (9)	446 (91)	483	378 (78)	42 (11)	336 (89)
Full primary or more	259	253 (98)	22 (9)	231 (91)	254	197 (78)	9 (5)	188 (95)
Population density								
$<1{,}000$ people/km^2	141	136 (96)	11 (8)	125 (92)	137	104 (76)	10 (10)	94 (90)
$\geq 1{,}000$ people/km^2	779	766 (98)	70 (9)	696 (91)	762	597 (78)	55 (9)	542 (91)
HH possessions SES factor∓								
More possessions	331	326 (98)	27 (8)	299 (92)	326	252 (77)	4 (2)	248 (98)
Fewer possessions	521	511 (98)	47 (9)	464 (91)	507	398 (79)	57 (14)	341 (86)
Animal SES factor∓								
More animals	164	161 (98)	14 (9)	147 (91)	161	127 (79)	14 (11)	113 (89)
Fewer animals	688	676 (98)	60 (9)	616 (91)	672	523 (78)	47 (9)	476 (91)
Deworming in last year								
Yes	266	265 (100)	37 (14)	228 (86)	263	215 (82)	26 (12)	189 (88)
No	638	631 (99)	43 (7)	588 (93)	629	482 (77)	39 (8)	443 (92)

[a]N is the total sample size that has data (i.e., does not include missing data).
[b]Participants self-reported either having or not having diarrhea in the past 7 days.
[c]Only persons ≥1 year of age had stool testing for STH because there was no WHO guidance for STH treatment in children <1 year of age (Montresor et al. 2003; WHO 2017a).
*Age group categories included PSAC 1–4 years old, SAC 5–14 years old, and adults ≥ 15 years old. This variable was only used in the diarrhea analysis.
†Age/sex categories included PSAC 1–4 years old, SAC 5–14 years old, WCBA 15–44 years old, and other adults ≥ 15 years old. This variable was only used in the STH analysis.
∓SES variables were determined by factor analysis of 18 variables concerning family member possessions (including possession of animals and animal types), education level of the mother, monthly household income, and household wall construction material. The analysis generated two factors: the first dealing with household possessions, mother's education, monthly income, and wall construction, and the second dealing with household possession of animals.

Table 2 | Univariable and multivariable logistic regression models for a cross-sectional survey of water, sanitation, and hygiene risk factors for STH infections and diarrhea in NSR, Guatemala – 2010

	Univariable			**Multivariable**		
Variable	**OR[a]**	**95% CI[b]**	***p*-value**	**OR**	**95% CI**	***p*-value**
STH analysis						
HH possessions SES factor = 1*	0.11	0.04, 0.34	<0.001	0.36	0.09, 1.52	0.16
Finished floors (vs. natural)†	0.18	0.08, 0.41	<0.001	0.16	0.05, 0.50	0.002
Water used for drinking, observed‡						
Bottled vs. improved	0.78	0.21, 2.96	0.72	7.16	0.76, 67.10	0.08
Other improved vs. improved	5.57	1.90, 16.36	0.002	7.00	1.22, 40.14	0.03
Unimproved vs. improved	6.09	1.52, 24.37	0.01	5.25	0.83, 33.37	0.08
Age/sex§						
WCBA vs. other adults	1.11	0.53, 2.35	0.78	0.97	0.42, 2.27	0.94
School-age children vs. other adults	2.38	1.22, 4.65	0.01	2.35	1.10, 4.99	0.03
Preschool-age children vs. other adults	1.43	0.59, 3.46	0.43	1.12	0.38, 3.34	0.84
Median number of people per bedroom >2.5‖	3.34	1.22, 9.09	0.02			
Water present at handwashing station, observed	0.33	0.14, 0.75	0.009			
Water present at handwashing station, observed, by median number of people per bedroom¶						
> 2.5				0.32	0.11, 0.98	0.05
≤ 2.5				3.47	0.62, 19.47	0.16
Diarrhea analysis						
Method for drying hands, observed#						
Use garment vs. air dry	1.91	0.73, 5.00	0.19	1.98	0.73, 5.39	0.18
Use towel vs. air dry	0.81	0.30, 2.20	0.69	0.88	0.30, 2.55	0.81
Time spent collecting water >10 min	2.22	1.19, 4.13	0.01	1.90	1.02, 3.56	0.04
Handwashing station within 10 m of sanitation facility	2.44	1.04, 5.74	0.04	3.69	1.33, 10.21	0.01
Age group**						
School-age children vs. adults	1.35	0.76, 2.39	0.31	1.30	0.71, 2.37	0.40
Preschool-age children vs. adults	3.07	1.72, 5.50	< 0.001	3.33	1.83, 6.04	< 0.001

[a]OR – odds ratio.
[b]95% confidence interval [CI].
*SES variables were determined by factor analysis of 18 variables concerning family member possessions (including possession of animals and animal types), education level of the mother, monthly household income, and household wall construction material. The analysis generated two factors: the first dealing with household possessions, mother's education, monthly income, and wall construction, and the second dealing with household possession of animals. Only the first factor was statistically significant in univariable analysis.
†Finished floors include wood, vinyl, ceramic tiles, cement, carpet, and brick. Natural earthen floors include sand, dung, straw, and sawdust.
‡Modified WHO/UNICEF Water Ladder (WHO and UNICEF 2010): unimproved water (unprotected dug well, unprotected spring, water cart, tanker truck, surface water); other improved water (public tap, borehole, protected dug well, protected spring, rainwater collection); bottled water; and improved water (piped household water connection located inside the dwelling, yard, or plot).
§Age/sex categories included PSAC 1–4 years old, SAC 5–14 years old, WCBA 15–44 years old, and other adults ≥ 15 years old.
‖Crowded homes defined as >2.5 people per bedroom, the median of people per bedroom in the dataset.
¶Due to the interaction between crowding and water present at the handwashing station in the STH multivariable model, results for water present at each crowding category are given. Univariable results are presented for each of these variables individually.
#Interviewer observed household spokesperson complete a handwashing demonstration and dry hands at the main handwashing place for the household.
**Age group categories included PSAC 1–4 years old, SAC 5–14 years old, and adults ≥ 15 years old.

households than uncrowded (OR 3.34, CI 1.22–9.09). Lastly, any water present at the handwashing station was found to be protective (OR 0.33, CI 0.14–0.75).

In Supplementary Material, Table S1, univariable STH results showed key hygiene associations, which included water used for handwashing from a container (OR 11.36, CI 2.69–47.93) or basin (OR 7.58, CI 2.26–25.41) vs. from tap, tippy tap (Watt 1988), sink, or pipe. Those with water available <6 h/day (OR 4.17, CI 1.58–10.98) and those who spent >10 min collecting water (OR 3.1, CI 1.36–7.07) also had higher odds of STH infection. See Supplementary Materials, Tables S1 and S2 for a complete list of variables, OR, 95% CI, *p*-values, and FDR-corrected *p*-values for the univariable analysis for STH infection and self-reported diarrhea.

All variables presented in Tables S1 and S2 were candidates for multivariable models, selected by group LASSO. Multivariable model results are presented in Table 2. In multivariable modeling for STH infections, SAC (OR vs. adults excluding WCBA: 2.35, CI 1.10–4.99) and the observation that the household drinking water supply came from an 'other improved' source (OR vs. 'improved': 7.00, CI 1.22–40.14) were the two factors associated with STH infection. Finished floors was a highly protective factor (OR vs. natural floors: 0.16, CI 0.05–0.50). Observing water present at the handwashing station also was protective for families in crowded households with a median number >2.5 persons per bedroom (OR vs. not observing water present: 0.32, CI 0.11–0.98).

For the diarrhea outcome, observing the household spokesperson washing hands at the main handwashing place for 31–60 vs. <5 s was associated with diarrhea in univariable analysis (OR 4.28, CI 1.70–10.75). Three other variables were also statistically significant in univariable analyses, but only these three remained in the multivariable model. After adjusting for the observed method of drying hands after handwashing, spending >10 min per round trip collecting water (OR 1.90, CI 1.02–3.56), being a preschool-aged child (vs. an adult) (OR 3.33, CI 1.83–6.04), and having a handwashing station <10 m of a sanitation facility (OR 3.69, CI 1.33–10.21) were all associated with a higher odds of diarrhea.

DISCUSSION

This study investigated WASH, demographic and SES factors associated with STH infections and diarrhea in NSR, Guatemala. The results of this study may be helpful to further the development of effective interventions to prevent these diseases. The main factors associated with STH infection identified in multivariable modeling were being a school-aged child, and the observation that the household drinking water supply was classified as 'other improved' vs. 'improved'. The identification of SAC as a demographic factor associated with STH infection is consistent with the known age-related pattern of STH infection. Multiple prevalence surveys have shown that the highest global burden of STH infection occurs among SAC (Pullan *et al.* 2014). The WHO/UNICEF drinking water ladder was designed considering both water quality and water quantity. 'Improved' and 'other improved' drinking water sources are those whose design and management were considered, based on evidence available in the early 2000s, to be more likely to result in protection from fecal contamination when compared with other 'non-improved' source types (WHO and UNICEF 2008). When our study was performed, there was growing recognition that the drinking water ladder categories in use at the time ('improved', 'other improved', and 'unimproved') insufficiently reflected deficits of water quantity and access, particularly in the 'other improved' category. Consequently, the most recent version of the drinking water ladder now better addresses water access and by extension water quantity (WHO and UNICEF 2017). Limited water quantity may partially explain the association we found between STH infection and 'other improved' water, which requires some degree of water transport into the household, and therefore limited water quantity, vs. 'improved' water that is piped directly into the dwelling or household yard or plot. Further supporting this association in multivariable analyses, we also found similar water quantity-related associations in our univariable analyses. Associations between STH infections and drinking water have been demonstrated in other studies (Nasr *et al.* 2013; Echazu *et al.* 2015; Matanock *et al.* 2018). However, some studies have found no associations (Freeman *et al.* 2015; Vaz Nery *et al.* 2019). Nevertheless, meta-analyses examining the effects of water treatment (filtered or boiled) and piped water access reported both lowered the odds of STH infection (Strunz *et al.* 2014). The mechanism of the effect of water on STH infections is not fully understood. It could be by direct contamination of water with helminth eggs, inadequate quantities of water for personal and environmental hygiene, or some combination. These mechanisms require further investigation to develop and implement effective water interventions for STH infections.

In our study, having a finished floor (wood, vinyl, ceramic tiles, cement, carpet, or brick) in the household was found to be a protective factor against STH infection compared with a natural floor (earthen, sand, dung, straw, or sawdust), even when controlling for SES factors. Other studies reported environmentally clean households had reduced *Ascaris* infections among household members, specifically children <5 years old (Lin *et al.* 2013). A study of STH infections in children in an urban slum in Kenya found that finished floors were protective (Worrell *et al.* 2016), and a study in rural Bangladesh found that finished floors reduced prevalence of *Ascaris*, but not *Trichuris* or hookworm (Benjamin-Chung *et al.* 2015). Soil floors were associated with *Trichuris* infections in males in a study in India (Narain *et al.* 2000), whereas soil floors were associated with both *Trichuris* and *Ascaris* infections in a study in Venezuela (Quintero *et al.* 2012). Given the composition of natural floors, microbes tend to have increased survivability in these environments. Attempting to clean these floors, any dust or dirt may be aerosolized more easily leading to further contamination of other surfaces and objects within the household environment, such as stored food and water (Worrell *et al.* 2016). By contrast, finished floors would be easier to clean, thereby reducing potential fecal contamination of the domestic environment.

STH transmission occurs via ingestion of or contact with infective parasite stages that are present in soil contaminated with human feces. This contaminated soil is ingested either directly (e.g., pica in young children) or more commonly through soil-contaminated food, water, hands, and other objects. These modes of transmission can be interrupted through safe and improved water access, adequate hygiene, and improved sanitation. Consequently, STH infections are assumed to be 100% attributable to inadequate WASH (Pruss-Ustun *et al.* 2019). Given the repeated findings that finished floors are protective against STH infections, we suggest that finished floors be considered and evaluated as a hygiene intervention, particularly given the inconsistent impacts that the WASH intervention trials to date have had on STH infections (Freeman *et al.* 2013; Patil *et al.* 2014; Vaz Nery *et al.* 2019). Modeling suggests that, when MDA programs are in effect, sanitation and hygiene interventions have little observable short-term impact on STH infection levels above those of MDA but that WASH interventions are vital for sustaining control or for eliminating STH infections long term (Coffeng *et al.* 2018). The installation of a tile, cement, or some form of finished floor (a singular, permanent intervention) could be an effective adjunct to such programs, particularly if cost-sharing schemes could be worked out. Additionally, this intervention does not require complementary health education or behavior change training. Further cost-benefit investigations of such interventions are warranted.

On multivariable analysis, after adjusting for observed hand drying on towels or garments by the household spokespersons, our study showed an association between diarrhea and time spent collecting water >10 min. This finding is supported by other data that have shown reduced time spent collecting water results in a 41% decrease in relative reduction in risk for childhood diarrhea (Pickering & Davis 2012) and an updated WHO/JMP definition of basic water service that is now defined as drinking water from an improved source and collection time of water was <30 min per round trip (WHO and UNICEF 2017). The associations we found between diarrhea and preschool-age children are also well-supported throughout WASH literature in that children <5 years are a vulnerable population to diarrheal disease (Lanata *et al.* 2013; Kotloff 2017). However, we were surprised by our finding that having a handwashing station within 10 m of a sanitation facility was associated with an increased odds of reported diarrhea. Although only in univariable analysis, we also found that observed handwashing time by the household spokesperson >5 s was also associated with diarrhea (31–60 s). Our findings with the handwashing station and the handwashing time seem counterintuitive, but handwashing behaviors in and of themselves are complicated interventions for diarrhea. There is more to a handwashing station than just the physical infrastructure; the presence or absence of soap and water and the uptake and adherence to handwashing behavior at the handwashing station are also important components that must be considered (Pickering *et al.* 2019). Our study observed the physical characteristics of the station and the presence of water, soap, and other cleansers. We also observed the length of washing and noted how hands were dried by the household spokesperson. However, we did not observe the same for all participants and know that 'observer bias' may explain the counterintuitive results. Therefore, we were unable to fully evaluate behavior at the handwashing station in question. Nevertheless, we do know that there were no statistical differences in the main types of household handwashing stations used by those with and without diarrhea (i.e., basins, pouring from containers, and taps/tippy-taps/sinks/pipes). Likewise, there were no statistical differences in the presence of soap or water at these stations. Soap was present in 86–93% of stations, but water was present only in 56–65% of stations. Other studies have shown that handwashing stations did not reduce childhood diarrhea, as a single intervention or combined with other WASH interventions, even after repeated monthly visits striving to reinforce behavior change over the course of 2 years (Null *et al.* 2018). Other large WASH intervention trials have also shown no impact of hygiene alone or in combination on diarrhea outcomes (Null *et al.* 2018; Reese *et al.* 2019; Rogawski McQuade *et al.* 2019). It is thought that the impact of WASH interventions on diarrhea depends on the concentration and type of fecal pathogens people are exposed to in their environments and the pathways by which they are exposed, of which there are many. An intervention that reduces fecal exposure by one transmission pathway might still not result in a measurable reduction in diarrhea incidence, particularly if other important pathways remain and if the level of fecal contamination in the environment remains high (Wolf *et al.* 2019). The positive association between hygiene and diarrhea requires further investigation.

Our measurement of diarrhea was less specific than our measurement of STH since diarrhea was self-reported, whereas STH was laboratory-confirmed by stool testing and therefore not subject to recall bias nor to personal interpretations, unlike the meaning of 'loose stool' for diarrhea. This may have affected our analyses and our detection of WASH associations with diarrhea, such as our results on hand washing and increased association with diarrhea. Also potentially affecting analyses were the statistical methods chosen for model selection. LASSO was used to select a suitable set of predictors for multivariable models but may have omitted strong univariable predictors due to correlations with selected variables (Zou & Hastie 2005). Group LASSO was used to select the variables represented in the multivariable models so that components of multiclass variables would be considered together, but a method for performing group LASSO while also taking into account survey weights could not be identified. However, after variable selection using LASSO (ignoring survey weights), multivariable model parameter estimates were calculated taking survey weights into account, and associations were similar in both the LASSO and survey models. This suggests that using a selection method including weights would have resulted in similar conclusions.

This study has several other limitations. For field logistical reasons, we used the FPC method, which is less sensitive than the Kato Katz method (Goodman *et al.* 2007). Additionally, this study used a definition of diarrhea that was being used by the Ministry of Public Health and Social Welfare for their surveillance system. This definition is not a standardized definition commonly used now and is thus more challenging to compare our diarrhea results to other studies. Two diarrhea-related variables were available: whether or not a person had loose stools in the last 7 days and whether or not a person had at least three loose stools on the worst day of the past 30 days. Since recall was expected to be unreliable when asking about the past 30 days, we focused on the 7-day variable. Another limitation was that information used in analyses was missing for a considerable number of subjects. While diarrhea status was reported for almost all subjects, a high proportion did not provide stool samples for STH testing. This missing information could affect model results and associations. Other variables also had missing data, with income having the highest proportion of missingness. This variable was used in the calculation of the SES possessions factor, so missing data could have had an impact on results if the missingness was associated with other factors. However, a missingness evaluation did not identify differences in those that reported income and those that did not and fitting the final multivariable model for the STH outcome without the SES possessions factor resulted in similar associations. Regardless, this data analysis demonstrates that finished floors have a protective effect and handwashing in crowded households decreases the odds of STH infection while drinking 'other improved' sources of water increases the odds of STH infection.

CONCLUSIONS

Our study found strong associations between STH infections and two factors: observed household drinking water supplies classified as 'other improved' and SAC. We found a highly protective effect against STH infections with finished floors and a protective effect in crowded households with observed water at handwashing stations. For diarrhea, we found associations between illness and three factors: preschool age (compared with adults), spending more than 10 min collecting water, and having a handwashing station within 10 m of a sanitation facility. Although our cross-sectional survey in Guatemala found mixed results regarding WASH risk factors for diarrhea, the strong protective association between finished floors and reduced STH infections may be additional data for both the WASH and STH/neglected tropical disease communities to further investigate the installation of finished flooring as an adjunct to more familiar interventions, such as increasing drinking water quantity through expanded water access and ensuring water at handwashing stations in crowded homes.

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DISCLOSURE

Findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the CDC.

DECLARATIONS OF INTEREST

None.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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