BEHAVIORAL AND BIOLOGICAL PLAUSIBILITY OF THE PROTECTIVE EFFECTS OF IMPROVED FLOORING

FINAL REPORT

PHOTO CREDIT: EARTHENABLE

DECEMBER 2021

This publication was produced for review by the United States Agency for International Development.

It was prepared by the EarthEnable with technical support from the Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability project.

ACKNOWLEDGMENTS

This study was conducted by a team from EarthEnable and made possible through a grant from the United States Agency for International Development (USAID) Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability (WASHPaLS) project: Grant No. WASHPaLS-G09-EarthEnable.

We would like to acknowledge the team of individuals who worked on the development of this report:

- Laura H Kwong, Principal Investigators, consultant
- Henry Nampala, interviewer and field staff supervisor
- Maya Homsy King, UC Berkeley MPH student

We also would like to acknowledge all the members of the research team: Gayatri Datar, Jonathan Byampola, Apollo Mukhama, Favor Bakaki, Hatimu Katerega, Isaac Ayika

We would like to thank all the study participants for their active participation.

Preferred citation: USAID and EarthEnable. 2021. Behavioral and biological plausibility of the protective effects of improved flooring. *Final report.* Washington, DC., USAID Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability (WASHPaLS) Project.

Cover photo credit: *EarthEnable*

Prepared for the United States Agency for International Development by the Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability (WASHPaLS) project, Task Order number AID-OAA-TO-16-00016 of the Water and Development Indefinite Delivery Indefinite Quantity Contract (WADI), contract number AID-OAA-I-14-00068.

Tetra Tech Contacts:

Morris Israel, Project Director
morris.israel@washpals.org

Jeff Albert, Deputy Project Director
jeff.albert@washpals.org

Lucia Henry, Project Manager
lucia.henry@tetratech.com

Tetra Tech
1320 N. Courthouse Road, Suite 600, Arlington, VA 22201
Tel: 703 387 2100, Fax: 802 658 4247
www.tetratech.com/intdev

BEHAVIORAL AND BIOLOGICAL PLAUSIBILITY OF THE PROTECTIVE EFFECTS OF IMPROVED FLOORING

FINAL REPORT

DECEMBER 2021

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

CFU	Colony Forming Units (estimates concentration of microorganisms in a test sample)
COVID-19	Coronavirus Disease 2019
E. Coli	Escherichia coli
ICC	Intraclass Correlation
MPN	Most Probably Number (coliform-group organisms per 100 mL of water)
UBOS	Uganda Bureau of Statistics
UGX	Ugandan shilling
USAID	United States Agency for International Development
USD	United States Dollar
VHT	Village Health Team
WASH	Water, Sanitation, and Hygiene
WASHPaLS	Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability

EXECUTIVE SUMMARY

BACKGROUND

Fecal matter and parasites, such as soil-transmitted helminths, are just some of the contaminants found in soil. Fleas and rats spread these toxins widely. Children are exposed to these pathogens, parasites, and vectors when they put soil-contaminated objects, including their hands, or soil directly into their mouths. Walking or sitting directly on earth floors creates another exposure point.

Exposure to fecally contaminated soil has been associated with enteric illness and growth faltering among infants and young children. Chronic parasite infections are associated with impaired cognitive development, school performance and earning potential. Hookworm infection is associated with anemia and can lead to adverse birth outcomes among pregnant women.

Compared to unfinished flooring, finished flooring may reduce children's exposure to pathogens. To explore how the behavioral and biological mechanisms by which improved flooring could improve child and maternal health, the field team conducted a three-part study of improved flooring in rural Uganda. In Part 1 of the study, EarthEnable conducted in-depth interviews to explore the perceptions of improved and unimproved housing material and how installation of improved flooring alters behaviors. In Part 2, EarthEnable assessed children's exposure to soil and other objects potentially contaminated with soil, as well as their time spent inside the house, to understand the degree to which improved flooring inside the house may impact children's health. In Part 3, EarthEnable measured the amount of dust on improved and unimproved floors to produce a quantitative estimate of finished flooring's potential to reduce exposure to pathogens.

METHODS

Part 1: To understand changes in behaviors associated with installation of improved flooring, EarthEnable conducted in-depth interviews with 39 individuals. The field team asked about housing material and preferences, shoe-wearing in relation to different types of flooring, floor cleaning practices, animal husbandry practices, the amount of time children and adult participants spend inside (and reasons why), changes in perception of health and well-being since installation of the floor, and changes in behavior since installation of the floor.

Part 2: To quantify children's interactions with the environment and the amount of time they might spend on an improved floor, the study team conducted between one and three six-hour observations of 122 children less than 59 months old and observed 22 pregnant women engaging in their normal daily activities at home. Using the LiveTrak software application, study personnel coded video recordings to record every hand- and object-to-mouth contact, the child's location, and other information.

Part 3: To examine the likelihood that children who lived in homes with improved floors have less exposure to pathogens in soil and/or dust than children in homes with unimproved dirt floors, EarthEnable measured the load of dust on improved and unimproved floors.

RESULTS

Part 1: Participants said that improved materials could protect the health and safety of children and adults who lived in the house, as well as visitors. They specifically mentioned how some materials harbor pests while others do not. They noted that some materials also shed dust, which they linked to an

increase in children coughing, in addition to soiling household items left in the open. Participants also reported that they consider some materials to be unsafe because they could catch on fire. In addition to factors related directly to health and safety, several other factors influenced households in their choice of housing materials, including affordability, availability of natural resources, convenience, durability, cleanability, beauty, comfort, modernity, and respect.

Part 2: Controlling for type of object mouthed (the act of a child putting something in his/her mouth), mouthing rates were significantly lower when children were inside as opposed to outside. Considering all age groups combined, children (who performed the behavior) mouthed their hands a median 31.3 times/hour, put objects in their mouths 8.7 times/hour, put food (excluding breastmilk) in their mouths 37.2 times/hour and drank liquids 6.1 times/hour. A total of 76 (34%) children were observed putting soil or ash in their mouths, with a median of 0.7 times/hour and 16 (7%) children were observed putting (human or animals) feces in their mouths, with a median of 0.2 times/hour. Nearly half (42%) of children less than 6 months old and nearly two-thirds (60%) of children 6-11 months old were observed mouthing soil; they mouthed soil approximately 1.6 times per hour. One-quarter to one-third of children 12-47 months old were also observed mouthing soil during the six-hour observation. Over 10 percent of children less than 11 months old mouthed feces during the observation, 2-8 percent of children 12-47 months old also mouthed feces. Pregnant women put hands in their mouths a median of 5.4 times/hour, put objects in their mouths 2.1 times/hour, consumed food 22.6 times/hr, and drank liquid 4.8 times/hr. A total of 10 percent of pregnant women also mouthed soil, and no mothers mouthed feces. Controlling for type of object mouthed and age group, children mouthed hands and objects less frequently inside than outside, but there was no significant difference in time spent inside or mouthing frequencies between those children that lived in homes with some improved flooring (the treatment group) and those who lived in homes with no improved flooring (the control group).

Part 3: The median load of dust on dirt floors was 141.1 g/m^2, which is almost 9 times higher than the load of dust on finished EarthEnable floors of 16.4 g/m^2.

DISCUSSION

Part 1: Installation of improved flooring is a one-time investment with very low maintenance requirements. In-depth interviews suggest that improved flooring is not only an enabling technology, but also a *motivating* technology that incentivizes households to maintain the clean, smooth, aesthetically pleasing surface of the improved floor. Maintenance behaviors include frequently sweeping and mopping, removing shoes before entering rooms, and prohibiting domestic animals from entering or sleeping in the room. Such behaviors likely reduce the amount of dirt and fecal matter tracked into the house or generated in the house; inversely, improved behaviors increase the amount of dirt and fecal matter removed from the house.

While participants reported largely positive changes in behaviors and perceptions associated with the floors overall, given the gendered nature of social norms and women's roles and responsibilities in cleaning, water-fetching, maintaining the home, and caregiving for children, future research should pay close attention to these shifts, and monitor for any associated sanctions or negative consequences, specifically for women. In addition, future research could quantify the impact of improved flooring on the amount of time and perceived effort women spend cleaning their homes, in conjunction with

perceived satisfaction and objective measurements of the loads of dust on floors. Other observations of gender-specific interactions with flooring are noted in the relevant sections throughout this report.

Part 2: The prevalence of mouthing observed among children in rural Uganda was substantially higher than has been observed for young children in Bangladesh, Zimbabwe, and Ghana. A limited amount of time spent inside and lower mouthing frequencies inside suggest that improving indoor floors alone may not be sufficient to dramatically reduce children's exposure to fecal contamination. In addition, the research team recommends that projects should combine improved flooring with other interventions to reduce fecal contamination of the outside environment, such as animal feces management.

Part 3: Substantially lower amounts of dust on improved floors compared to unimproved floors, along with prior evidence that soil on improved floors is less contaminated than soil on unimproved floors, suggest that children who spend time on improved floors have substantially lower pathogen exposure than children who spend the same amount of time on unimproved floors.

CONCLUSION

While children spend most daylight and evening hours outside the house and have lower mouthing frequencies inside as compared to outside, the feasibility and appeal of improved flooring, changes in hygiene-related behaviors in households with improved floors, and lower loads of dust on improved floors suggest that improved floors are a motivating technology and could be combined with interventions, such as animal feces management, to support more hygienic environments for infants and young children. To increase uptake of improved flooring, implementing organizations and market actors should frame affordable, non-concrete improved floors as aspirational endpoints rather than steppingstones. Additionally, implementing partners should discuss some of the gender-specific non-health benefits such as reduced workload and increased status and respect with the collaborating communities.

1.0 BACKGROUND

Soil can be contaminated with fecal matter and parasites, such as soil-transmitted helminths. Soil and dirt can also harbor vectors like fleas and rats. Children can be exposed to these pathogens, parasites, and vectors when they put soil or soil-contaminated hands or objects into their mouths or touch soil with their bare skin, for example while walking barefoot or sitting on dirt floors (Kwong, Ercumen, Pickering, Arsenault, et al. 2020). Exposure to fecally contaminated soil has been associated with diarrhea, enteric enteropathy and growth faltering among infants and young children (Shivoga and Moturi 2009; George et al. 2015). Chronic parasite infections are associated with impaired cognitive development, school performance and earning potential (Owada et al. 2017; Ezeamama et al. 2005; Ziegelbauer et al. 2012; Guyatt 2000). Hookworm infection is associated with anemia and can lead to adverse birth outcomes among pregnant women (Mpairwe, Tweyongyere, and Elliott 2014)

When homes have dirt floors, pathogen exposure from pathogen-laden soil can occur both inside and outside of the house. One way to reduce exposure to soil and soil-borne pathogens is to replace natural or rudimentary floors (collectively called "unimproved" floors) with finished ("improved") floors. The demographic and health surveys implemented by USAID define natural floors as those made of earth, sand, clay, or dung, and rudimentary floors are made of wood planks, palm, bamboo, mats, or adobe. Finished floors are those made of stone, brick, ceramic, polished wood, vinyl, linoleum, or carpet (Florey and Taylor 2016). There is limited observational evidence that improved floors are associated with improvements in child health. In a study of 2,755 urban Mexican households, concrete floors were associated with a 49 percent reduction in child diarrhea, a 78 percent reduction in child parasitic infection, and an 81 percent reduction in child anemia compared to dirt floors, as well as improved cognitive development outcomes and reduced adult depression (Cattaneo et al. 2009). While the Mexico study did not examine children for bacterial or viral infections, the authors hypothesized that the health improvements were driven by reduced amoebic infections. In their conclusion, the authors noted that the positive correlation between cement floors and decreased diarrhea, parasitic infection, and anemia may not be generalizable beyond an urban context where there is a baseline high prevalence of improved floors and piped water access, as well as a population of relatively well-nourished children.

This and other evidence suggests that it is possible that improved floors in homes are necessary, in combination with other improved housing materials or water, sanitation, and hygiene infrastructure, to achieve low levels of diarrhea, but by themselves are not sufficient. These studies raise the question, "to what degree do other household materials need to be improved, or what other water, sanitation, and hygiene infrastructure needs to be in place in the home or community, to improve child health?" One observational study in rural areas has found similar associations between improved flooring and improved child health outcomes, suggesting that at least in some rural areas, a combination of building materials, water, sanitation, and hygiene infrastructure, and other factors associated with improved flooring correspond with lower rates of infections. In rural Bangladesh, a study of nearly 16,000 households found that improved floors were associated with a 44 percent reduction in the prevalence of infection with *Ascaris lumbricoides.* There was no association with reduced infection of *Trichuris* or hookworm. The authors also noted a synergistic effect of deworming and finished flooring in decreasing infection with *Ascaris* (Benjamin-Chung et al. 2021).

To explore how the behavioral and biological mechanisms by which improved flooring could improve child and maternal health, EarthEnable conducted a three-part study. In Part 1 of this study, EarthEnable conducted in-depth interviews to explore the perceptions of improved and unimproved housing material and how installation of improved flooring alters behaviors. In Part 2, EarthEnable assessed children's exposure to soil and other objects potentially contaminated with soil, as well as the amount of time children spend inside the house, to understand the degree to which improved flooring inside the house may impact children's health. In Part 3, EarthEnable measured the amount of dust on improved and unimproved floors to produce a quantitative estimate of finished flooring's potential to reduce exposure to pathogens. To ease readability, this report presents the introduction, methods, results, and discussion of each part separately. This report focuses on the impact of finished flooring, in some cases a particular type of finished flooring developed by the company EarthEnable. This report is not intended to advocate for EarthEnable floors above other forms of finished flooring. EarthEnable floors are the most affordable option for durable finished flooring in East Africa, so this report examines their impacts as indicative of potential impacts of any type of finished flooring.

Box 1: A finished floor that is feasible, affordable, and durable: EarthEnable floors

EarthEnable floors consist of a compacted layer of laterite, a material locally available in East Africa, topped with a compacted mixture of sand and clay. A proprietary varnish (oil) is then painted on the top surface. It permeates the combined sand and clay layer and forms a water-resistant, plastic-like, shiny resin on top. The result is an affordable, shiny, smooth finished floor. EarthEnable is based in Rwanda and has operated in rural Uganda since 2016. More information on EarthEnable floors, a demonstration of how they are constructed, and the social enterprise that is scaling them across East Africa, visit https://www.earthenable.org/.

2.0 PART 1. PREFERENCES FOR, ADVANTAGES AND DISADVANTAGES OF, AND CHANGES IN BEHAVIOR AND WELL-BEING ASSOCIATED WITH HOUSING MATERIALS, WITH AN EMPHASIS ON IMPROVED FLOORING

2.1 INTRODUCTION

While there is some physical evidence that improved floors may reduce exposure to fecal contamination because they retain less moisture and are smoother than unimproved floors, there is currently a gap in research examining the relationships between improved flooring and the types and degree of behavior changes triggered by or associated with improved flooring. Questions include: how does improved flooring support or enable behaviors that may protect child health? What factors lead households to make improvements in their flooring or other aspects of household infrastructure? EarthEnable conducted semi-structured interviews to investigate child and adult behavioral modifications resulting from installation of improved flooring. The research team also examined motivations for and barriers to improving household infrastructure among household members in eastern Uganda. Between 70-75 percent of rural households in the study have unimproved floors (Uganda Bureau of Statistics (UBOS) and ICF 2018).

EarthEnable has worked in eastern Uganda since 2016 to deliver improved earthen floors. The company markets and installs flooring made from compacted local materials that are then treated with a proprietary varnish to create a smooth and water-resistant finish.

2.2 METHODS

2.2.1 Qualitative Approach

The research team applied a grounded theory approach, asking general questions about household infrastructure and how that infrastructure may influence health and well-being. The study investigated the following questions:

1. What housing materials or characteristics are thought to influence child and adult health? How do these perceptions relate to the type of materials preferred for construction? What are the barriers to using these preferred materials?
2. In addition to factors related to health and safety, what leads households to make improvements in their flooring or other aspects of household infrastructure?
3. How does improved flooring support or enable behaviors related to improved child health?

2.2.2 Data Collection

During the 2020 dry and wet seasons, one qualitative interviewer fluent in relevant local languages, conducted semi-structured, in-depth interviews with male and female heads of households in Luuka and

Inganga Districts in eastern Uganda. Interviews were held mostly in the local language of Lusoga. Some components of the interviews and some interviews were conducted in Luganda.

Participants saw the interviewer around the village while he was organizing video observations of the daily life of pregnant women and children under 5 years old, a part of this study discussed in Sections 3 and 4. Villagers knew the interviewer was interested in learning from community members about health-related issues and the interviewer reported that potential participants were eager to share their opinions.

The field team approached potential study participants (meeting criteria described below) face-to-face to ask them to become involved with the research. Participants were told that the interview would be about how they perceived floors impacting their well-being and more generally how household infrastructure influences hygiene and health. The interviewer shared some personal information with the participants to establish mutual trust. He shared information about his tribe, clan, and the name of the village where he grew up. None of the participants refused to participate.

Interview guides were developed iteratively by the principal investigator and the field staff coordinator/interviewer. The first version of the interview guideline explored questions such as housing material and preferences, shoe-wearing related to types of flooring, floor cleaning practices, and animal husbandry practices. In the process of developing and pretesting question guides, the field team heard anecdotal reports that families with EarthEnable floors no longer let their chickens inside the house. Therefore, the research team asked about animal ownership, where animals stay at night, and whether animals were allowed to walk on or sleep on improved or unimproved floors in the home. The first version of the interview guideline was piloted with three women.

After preliminary analysis of the responses to the first version of the survey, EarthEnable revised the guidelines to remove questions which had reached response saturation. The team replaced these questions with new questions that arose from the first set of interviews. A second, revised version of the interview guidelines explored some of the previous topics, as well as the reasons and amount of time children and the participants spend inside, changes in perception, and changes in behavior since installation of the finished floor. The second version of the interview guidelines was piloted with one woman. On average, interviews lasted approximately one hour. The research team concluded interviews when the study reached data saturation. At that point, additional responses did not add new information. There were no repeat interviews.

2.2.3 Sampling Frame and Sample Size

Earth Enable initially planned to conduct 30 interviews with individuals that lived in homes with only unimproved (dirt) floors and 30 interviews with individuals that lived in homes with improved floors. Given prior experience, the study team expected that data saturation would be reached after interviewing 20 to 30 individuals. Participants were selected from a baseline listing of households prepared for a related study on participant's willingness to pay for the EarthEnable floor. The list contained information about houses that had children under the age of 5 and the percentage of their total floor that was improved. To select the households with improved floors, the research team gathered a list of all households that had improved flooring on greater than 50 percent of their floor; there were 65 such households. To select the households with unimproved floors, the team collected a

list of all households with dirt floors located in the same villages as the selected households with improved floors. Then, the team randomly selected 30 of the houses with dirt floors.

Through initial visits and conversations with the village health teams, the research team learned that many households do not have children under 5 years old. Some households had a child under5 years old at the time of the baseline survey but by the start of this study, the child was older than 5. Some households reported that they sometimes had children under 5 years old visit their house but they had not recently been primary caregivers of children under 5.

While the study team had planned to interview individuals from houses with more than 50 percent of their house covered with improved floors, as well as individuals from houses that had only dirt floors, pilot interviews demonstrated that individuals who had never experienced improved floors had difficulty visualizing the floors or conceptualizing their potential impact. While they could try imagining what an improved floor would be like, they lacked the lived experience to put their dirt floors into perspective. This initial piloting led the research team to shift participant selection to individuals that lived in houses with some (but not all) improved flooring, and eliminate dirt only households from the methodology.

Hence the study team focused on enrolling individuals who had lived in houses with dirt floors and had added one or more rooms of improved flooring. People living in this type of home could readily compare their experiences with and without an improved floor and could speak to why they had not improved all the floors in their household, despite having chosen to improve one or more of them. In total, the study team conducted interviews with 46 individuals (22 males and 24 females) that lived in homes with 'mixed' flooring including one or more rooms with an improved floor. There was one target respondent per interview, though sometimes a spouse was nearby and would offer some opinions.

The study team recognizes that women who are not the head of their household may not have access to or control of money to independently purchase flooring. As such, women may be required to make decisions jointly with male adults or convince the male adult decision maker of the improved floor's value. To address this, we interviewed both men and women about the factors that influenced their decision to install improved floors.

2.2.4 Analysis

Interviews were audio recorded, but transcriptions were not prepared. Instead, the interviewer listened to the audio recording and prepared summaries in English. The summaries were reviewed by Co-PI Laura H. Kwong, and the interviewer was requested to add direct quotes or details to specific responses. These summaries were not shared with the participants for comment or correction. Laura H. Kwong summarized the data by question, and Henry Nampala and Maya Homsy King reviewed the summary. Data was organized by themes identified *a priori* as well as themes that emerged throughout the research. Formal coding was not conducted.

2.2.5 Ethics

Participants provided informed, written consent prior to the interview. Face-to-face interviews were conducted at participants' homes. A spouse was often present during the interview, and children were occasionally present as well. This study was approved by the Mildmay Uganda Research Ethics Committee (REC REF# 0403-2019) and Makerere University (REF# SBS-730). Stanford University deemed that the Stanford affiliated researcher's participation in the study did not warrant Stanford IRB review.

2.3 RESULTS

2.3.1 Participants

The first version of the interview guideline was used with 30 participants (15 men and 15 women), all of whom were the parents or grandparents of children less than 5 years old at the time of the interview. Six households had no children less than 5 years old. All but one participant had a home with improved flooring on more than 50 percent of the household's floor surface. Improved flooring consisted of either concrete or EarthEnable floor. The second version of the interview guidelines was used with 16 participants (seven men and nine women); 12 of these participants were the parents or grandparents of children less than 5 years old at the time of the interview. All participants of the second iteration interview had floor surfaces that were made of more than 20 percent EarthEnable flooring.

2.3.2 Characteristics of Housing Materials that Influence Health and Safety

The survey questions captured participant perceptions of a range of building materials used for floors, walls, and roofs. Participants identified both positive and negative attributes. Participants readily discussed the topic and said that improved flooring materials could protect the health and safety of children and adults who lived in the house, as well as visitors. They specifically mentioned how some materials (discussed in more detail below) harbor pests while others do not. Participants also said that some materials shed dust and cause children to cough in addition to dirtying household items left in the open. Some materials were also considered unsafe because they can catch on fire.

Participants' quotes in the following sections include basic biometric information as well as the household reference number used by the field team.

Ability to harbor pests

Walls and floors made of soil, and roofs made of thatch, were perceived to negatively impact health and well-being because they harbor pests. Snakes, rats, fleas, maggots, jiggers, and ants dig holes and sometimes live in the cracks and pockmarks of dirt floors. Similarly, thatched roofs are hospitable habitats for rats, fleas, snakes, and other pests. Not only do pests themselves present a health hazard, but the strategies used to eliminate pests from the house are often hazardous: some participants reported that to kill pests by spraying their floors with insecticide and pouring boiling water, engine oil, or kerosene (paraffin) in the holes where pests live. Participants also use smoke to suffocate pests in their holes and smear the floor with cow dung to cover holes. Participants commented that the primary advantage of using improved housing materials is their potential to prevent pests. One participant shared:

> *This concrete floor doesn't harbor insects or parasites like the dirt floor. For example, sometimes when the children sleep on the floor the maggots, bedbugs, fleas, and other parasites attack them. The concrete floor does not harbor [pests]. Also, the rats can't easily damage the concrete floor by digging holes [in it] like the way they do in a dirt floor. If you do see this happening on the concrete floor then you know that the floor is too old* (Female 32-years-old, hh211033).

Participants reported that when pests such as rats and snakes do enter a house, they are easy to spot on improved materials like burnt brick walls and finished floors and can be quickly killed or removed from the house.

Dustiness

Walls and floors made of soil also produce a lot of dust when swept. One study participant noted the effect that dust from dirt flooring has on children:

> *The advantage [of an improved floor] is that when you sweep your floor, the dust does not rise off the ground to reach the things that are in the house. With the dirt floor, the dust always lifts off the ground such that it makes other things in the house dirty. [With the improved floor] the amount of dust doesn't make the clothes on the hanger dirty and, whenever I sweep, the children are no longer affected as much by breathing in the dust* (Female, 45 years old, hh211252).

Sweeping often pushes dust into the air where it covers all visible surfaces, including bedsheets, clothing, plates, utensils, and furniture. While some study participants intentionally pour water on their floors to keep dust down, sweeping kicks up dust that then coats all surfaces. One male participant told the research team:

> *It used to be that as we swept [the dirt floor], dust would spread everywhere. Even a clean shirt that you hung on the wall, if you shook it a little, you easily saw that dust had settled on it. We no longer experience such issues anymore. We even used to wash plates from the cupboard before using them, because so much dust would have settled on them* (Male, 66 years old, hh11482).

During interviews, participants mentioned that one notable advantage of improved walls and floors is that they prevent all household items from becoming coated with dust. One participant reported that since installing improved flooring in at least some rooms of her house, her children do not have as many respiratory problems because they inhale less dust.

Flammability

Another characteristic of housing materials that could affect health and well-being is flammability. In this context, unimproved walls and floors are made of soil and not tarp or other flammable material, so participants' concerns about flammability applied only to the roof. One participant said that thatched roofs easily catch on fire from lanterns, oil burned to keep mosquitoes away, or arson, saying:

> *We always use paraffin [kerosene] and a small lantern. There is a higher risk of burning down the house because sometimes the children can't be so cautious and end up burning the whole house or even some of them dying in fires but when you have an iron sheet roof there is no way where a child can burn the iron sheets* (Male, 43 years old, hh211221).

2.3.3 Other Factors that Influence Household Improvements

In addition to factors related directly to health and safety, there were several other factors that influenced households in their choice of housing materials. These include affordability, availability of natural resources, convenience, durability, cleanability, beauty, comfort, modernity, and respect.

Cost

Participants cited cost as the primary advantage of unimproved materials. Unlike improved floors, dirt floors do not need specialized materials or labor to construct. They are a budget-friendly and accessible choice for poor households. Some households spend money on cow dung to smear on their dirt floors

to create a smooth surface, yet most households have their own cow dung that can be used for this purpose. Similarly, the materials necessary for walls made of wattle and daub (sticks and mud) require no financial investment. Participants said that most people use free materials to construct a house. Participants said it is not common for people to have enough money to buy improved materials like corrugated iron roofs (approximately 600,000 UGX [$162 USD]), burnt bricks walls, and concrete or EarthEnable floors. While EarthEnable floors were approximately a third of the price of concrete floors (per unit area), survey participants were not familiar with their quality. EarthEnable floors are sometimes prone to water damage, so some households expressed a desire to save up for more durable concrete floors rather than invest in EarthEnable floors.

Availability of natural resources

Families that cannot afford iron make their roofs with elephant grass thatch. When available, elephant grass is free. However, roofs must be replaced approximately every three months with 200 bundles (approximately 2 kg each) of grass each time. Another benefit of thatch is that it is quiet even in the rain and cool even in the heat. Participants said that a cool room is most important when a member of the household has a fever. In addition, while thatch roofs sometimes leak, they stay fastened to the house even in strong wind, unlike iron roofs which are known to blow off and hurt people. One participant also suggested that people might choose to live in a thatched house because of tradition: "It depends on cultures. Some people can afford a better home but because they want to preserve their culture, they remain in such [thatched roof] houses" (Male, 67 years old, hh211188).

Some households also reported that the market does not always have sticks and elephant grass for purchase, preventing them from building with traditional materials like wattle, daub, and thatch. The unreliable market for natural resource is most likely related to resource overuse and a preference to turn land normally populated by these plants over for sugarcane farming, the area's primary cash crop. One male participant shared:

> *Nowadays, times have changed and the population has grown so we no longer have unoccupied land where we can go and we look for that elephant grass, which we used to have in plenty, that we used to use for a grass thatched roof. In the past, this grass used to grow on its own on the unused land, so it was plentiful. This is not the case anymore. The second thing is that here in the Busoga region, we no longer have many trees or bamboo sticks to use as poles for a grass-thatched house. We also have no other option but to use modern materials since they are the only ones available* (Male, 62 years old, hh11482).

Convenience

Participants reported that convenience influences their preference for certain materials. Dirt floors are more convenient because they absorb water used for handwashing before a meal. One woman said:

> *When you wash your hands, you don't need to go outside of the house or get a bucket to wash hands from. You only wash from [inside the house] and the soil absorbs the water. But for the concrete floor you need a bucket to wash your hands* (Female, 65 years old, hh209031).

Participants also reported that EarthEnable floors are considered inconvenient because of rules related to their installation and maintenance. For example, after installation, residents cannot enter the room with new flooring for 10 days while the material cures. The floors cannot withstand heavy or sharp

objects, and may be damaged if water or liquid, such as urine, pools on the floor. The varnish also emits an unpleasant smell while it cures, a process which lasts about 10 days.

> *The material of EarthEnable they use while constructing the floor is called varnish. It smells so bad for a long time [while it cures]. But with a concrete floor, when it is done being constructed you just enter. So, with the EarthEnable floor the instructions and directives are very many whereby you're told you have to take like two months without mopping it* (Male, 48 years old, hh214282).

Durability

Participants appreciated the durability of specific housing materials. They reported preferring corrugated iron because it lasts longer than thatch and can be used to catch rainwater for reuse. They also preferred burnt brick walls held together with a mortar of sand and a binder (cement or salala, a by-product of sugar cane) because they are stronger than walls of wattle and daub. Termites often weaken wattle and daub walls by chewing at the poles. Wattle and daub walls are also not water resistant and rain sometimes washes away the mud, dirtying the house as the wall dissolves. While both concrete and EarthEnable floors crack with over time with use, participants preferred concrete because rats cannot bore into the flooring, unlike EarthEnable floors. One man mentioned that one reason concrete floors are preferred over EarthEnable floors is because concrete floors are more durable:

> *It is not easy for rats to dig holes on the concrete floor whereas for the EarthEnable floor they do dig, so that means the EarthEnable floor is not long lasting as compared to the concrete floor* (Male, 30 years old, hh214256).

Comfort for residents and guests

The comfort of household members and guests is also a factor in participants' decisions to use improved house materials. Participants said they feel much more comfortable hosting visitors on improved floors as compared to dirt floors. Smooth floors deter insects, and without the cracks, pits, or pockmarks of dirt floors, visitors can sleep comfortably, and furniture sits balanced and steady on the floor. Participants also suggested other home improvements that could increase comfort. With iron roofs, for example, increasing the height of the roof helps to keep radiant heat above the main living space. Installing metal doors also adds a level of security to the household.

In selecting which room to install a new floor, household members carefully considered the relative comfort their household residents and guests would enjoy. While some prioritized improving the flooring in the sitting room to benefit guests or the family, others prioritized their own room, children's rooms, or rooms that they rented out. One grandfather told the research team, "I chose [the materials I use for my house] such that I could be away from all that dust, and I chose [to improve the floor in the living room, where visitor's stay] because if I happen to host any visitor he or she should not be exposed to the dust" (Male, 75 years old, hh211483). A father said, "I started with the children's room because they were suffering a lot with diseases and the sitting room because it's where everyone eats from" (Male, 43 years old, hh211221). One mother shared that she chose to have the EarthEnable floor constructed in her bedroom "because in the bedroom is where I sleep and it is mostly where I am attacked by rats and cockroaches" (Female, 32 years old, hh211033).

Cleanability

The ability to clean floors thoroughly was also important to participants. Loose dirt is easier to spot on improved floors compared to dirt floors and it is also easy to clean improved floors as compared to dirt floors. One participant said:

> *[An EarthEnable floor] doesn't get as dirty as a dirt floor. When you sweep [a dirt floor] the dust lifts off the ground and coats the bedsheets and the clothes in the house and you have to do the laundry all the time. The cemented one [the EarthEnable floor] doesn't get as dirty. To clean it up you just get a cloth and mop it and the dust doesn't lift into the air* (Female, 32 years old, hh 211033).

Most women reported that having an improved floor made the house feel cleaner and more organized. With improved flooring, laundry does not attract as much dust and is easier to clean. Very few participants had both EarthEnable and concrete floors installed. Based on their observations about both flooring types, they preferred EarthEnable floors slightly less than concrete floors. Participants noted that EarthEnable floors are not as smooth as concrete floors which leads households to expend more energy to clean them as compared to concrete floors. Additionally, EarthEnable floors need to be dry during the post-installation curing process and cannot be mopped. Participants reported confusion about when they can start to clean and mop after installation.

Beauty

While not explicitly mentioned by many participants, a few male and female survey respondents indicated that aesthetic beauty a factor in their preferences. They noted the beauty of burnt brick walls over wattle and daub and the appeal of the shine of concrete. They also mentioned future home improvements they had begun to think about after installing an EarthEnable floor and several of these centered on matching the beauty of an EarthEnable floor, unifying the house, and eliminating pests, such as installing improved floors in all of their rooms, plastering their walls, and adding glass windows to the house.

Modernity/Respect

A few participants suggested that being perceived as modern or otherwise being respected by others influences the materials they select for their homes. Some participants said that cultural expectations, marriage, and transitioning from tenancy to home ownership led them to leave their former houses, but others said they were motivated to move into a new home largely because of a desire to improve the material quality of their home. Some, mostly men, said they want a house made of materials to demonstrate their wealth (such as an iron roof) or otherwise signify they had a home of a "higher standard." Others, men and women, specifically noted a desire for a house with the "trendiest" (i.e., newest, most popular) materials they could afford, or at least a house that was "strong" and "beautiful."

One respondent said that visitors compliment his family's hygiene because of the improved floors. He also said the improved floor benefit his children's health.

> *Nowadays when I host visitors and they sit in the sitting room, they all say, 'You really did good'. They even give me courage, telling me, 'If God gives you more money, then you can finish the remaining area.' There is also a lot of good hygiene and a big difference in my children's health*

because they used to get sick and jiggers would disturb them, but now they no longer fall sick (Male, 60 years old, hh213183).

2.3.4 Changes in Behaviors Following Installation of Improved Flooring

Participants reported adopting new behaviors after installing an EarthEnable floor. To prevent water damage, for example, adults and children no longer set jerry cans of water on the floor or pour water onto the floor after washing their hands. To prevent denting or penetrating the top layer of varnish, participants with improved floors take care not to place sharp objects, such as hoes or furniture with pointy feet on the floor. These practices were all recommended by the EarthEnable installers. Importantly, participants also reported changes in adult and child behaviors beyond practices related to floor management. For example, increased bathing, more frequent changing of clothes, increased cleaning and spatial organization, and changes in laundry frequency suggest that the presence of the improved floor shifted perceptions about personal hygiene and/or agency.

Adult and child personal hygiene and organization

Some adults reported changing their behaviors to match the cleanliness associated with the new, improved floor. Prior to installing the EarthEnable floor, one woman said that she used to put her soiled gardening clothes back on after she returned from the garden and showered. She knew the dust in her home would quickly make her clothes dirty so there was no point in putting on fresh clothes. However, after the improved flooring was installed, she started changing into fresh clothes after she showered because she "wanted to look as nice as the floor is, such that everything is nice, not only the floor" (Female, 36 years old, hh212151).

Another woman shared that having a clean EarthEnable floor encouraged her to change into clean clothes and spend more time organizing her space:

> *The way this house looks these days with the floor that is very clean. [If other people] find that still you are dirty and wearing dirty clothes, people wouldn't see sense in you. They'd say 'Ehh this lady is really very dirty. Even the dirty clothes from the garden–can't she at least remove them and wear clean clothes and stop throwing dirty clothes on this floor?' Nowadays…I make sure the house is very organized* (Female, 34 years old, hh14871).

Another man mentioned:

> *"[With my improved floor] there is also a lot of good hygiene and a big difference in my children's health because they used to get sick and jiggers would disturb them, but now they no longer fall sick* (Male, 60 years old, hh213183).

Some participants said that their older children began bathing more frequently after the family installed an improved floor. One participant said that her children "try [to clean] themselves more than before… because they don't want to be associated with dirty things when the floor itself is clean… [They changed their behavior] because of the standard of cleanliness of the house we are [now] living in." (Female, 36 years old, hh212151). If children were to be punished for not being clean enough, women would likely be the ones to punish them, but punishing children for not being clean enough was not reported.

Household organization

Participants also spoke about how their views on the cleanliness and organization of the space had changed since installing the floor. One woman said, "the reason I never used to feel [clean] is that the rats used to come into this house and spoil everything by digging everywhere, which caused all this disorganization" (Female, 36 years old, hh212151). Some adults also reported changing their behaviors to match the tidy aesthetic created by the improved floor. For example, one woman said she began to organize her household items to encourage her family members to also organize and be clean. Another woman went so far as to improve other aspects of her home to match the improved floor's more organized and clean feeling. One man reported assigning specific roles to rooms in his house, whereas before the improved floor, rooms did not have specific functions.

Some participants also reported that their children stopped throwing trash on the floor. One respondent said, "when they eat from the house these days [after the improved flooring was installed], they make sure they don't leave any rubbish in the house; they remove the rubbish." (Male, 60 years old, hh213183). One grandfather added:

> *In those days [before the improved floor was installed], you would find the mugs and other things disorderly, but now that is no longer the case. Now you can find someone who has just come from the garden going to wash his feet before entering the room. When they finished constructing [the EarthEnable floor] in those two rooms, the cleanliness was just inevitable* (Male, 66 years old, hh11482).

While some adults said they directed their children to change their habits or punished their children if they continued to discard trash on the floor, some children followed the example set by others in the household. Participants reported that some children simply want to be clean and improve the family's image. Children sometimes reminded each other to change their behavior as well:

> *Yes, nowadays the young ones usually remind each other, in case there is one of them who forgot to remove the shoes, not to step on the improved floor…they have changed according to how the situation has changed…by stopping the issue of bringing into the house their playing items like the tins and other things* (Male, 60 years old, hh204152).

Shoe removal, sweeping, and laundry

Participants reported that adults and children take their shoes off upon entering a house with an improved floor in order to maintain the cleanliness of the floor. In some cases, adults instructed their children to start taking their shoes off before entering. In other cases, children spontaneously adopted the habit of removing their shoes before entering. One man explained, "yes we remove [our shoes], so that on rainy days we avoid making the floor muddy and on sunny days we [don't make] the clean floor dusty" (Male, 67 years old, hh211188). These habits mirrored reports on shoe-wearing behavior while visiting others' homes. For example, participants said that if they go to a house with a dirt floor, they do not remove their shoes upon entering unless the host has a carpet at the door. In contrast, they said they their shoes if the host's house has an improved floor, unless the floor is visibly dirty.

To maintain the cleanliness of the improved floor, most participants also said they sweep more often than they did when they had dirt floors. One woman explained:

> *I used to sweep it [the dirt floor] once a day, but now [with the improved floor] I sweep like three times a day because every time someone walks around and the dirt remains on the floor you just feel that you should clean it. So nowadays I sweep and mop more than necessary* (Female, 38 years old, hh212125).

While some women sweep their improved floor more frequently than their unimproved floor, they did not necessarily perform more total work. An improved floor is much easier to sweep because it is smooth, and the even surface makes it obvious when the task is done. Sweeping a dirt floor can be very time-consuming because it is hard to clean all the pits in the floor. It is also more difficult to tell when all loose dirt has been brushed away.

The improved floor also led to changes in laundry frequency. Since sweeping improved floors kicks up less dust than sweeping dirt floors, many participants said that freshly laundered clothes accumulated less dirt after the improved flooring was installed. As a result, women launder less frequently and use less soap to wash the laundry compared to when they had dirt floors. Several women reported washing their clothes four times per week before installing the floor and three times a week after installing the floor. One man explained that his household saved money because they didn't have to purchase as much soap, a savings of approximately 1,000 Ugandan shillings ($0.25 USD) per bar. "All I know is that those days a full piece of soap would be used up in a day, but now it takes as many as three days to use up a bar of soap" (Male, 66 years old, hh11482). On the other hand, a few participants reported that they washed clothes once or twice per week because they found it difficult to keep clothes clean regardless of other hygiene practices. Buoyed by the hope that they could manage to keep clothes clean after the installing the improved floor, they increased their washing to three times per week.

Removing animals from the house

In a few households, participants reported changing their animal husbandry practices after installing the EarthEnable floor. Many participants noted, "it is not right to stay in the same house with the animals" (Male, 75 years old, hh211483), but they nonetheless allowed their chickens to stay inside the house at night to avoid theft. However, a few people said they no longer allow their chickens in rooms where improved EarthEnable flooring is installed. One said, "The reason I don't want to allow them to sleep on the EarthEnable floor is that I don't want them to spoil my floor [by urinating and defecating on the floor]" (Female, 32 years old, hh211033). Another man reported:

> *Now, after we constructed the [improved] floors we have specific roles for every room, which wasn't the case [before]... The chicken used to sleep in the house but nowadays we no longer let them sleep in the house because of the changes that happened* (Male, 60 years old, hh204152).

Children's use of indoor space

Participants said that adults generally decide when and why their child should be inside or outside the house and typically did so until a child is 16-18 years old. The research team observed that children spend most of their daylight hours outside. Participants said that children are generally not allowed to be inside during the day. One man commented:

> *[The children] are always [outside] in the compound in the shade playing. They only come to the kitchen when they are feeling hungry. They are never in the sitting room and also don't stay in their [bed]rooms"* (Male, 43 years old, hh211221).

Many caregivers said if a child is inside without a clear reason, the child is most likely sick or unhappy. In either case, the child is instructed to go outside to avoid "spoiling" the house, i.e., making the house dirty and/or disorganized. Participants said there are specific times when children should be inside, including after dark and when there is rain. According to participants, children should be inside after dark to avoid potential harm including snake bites, beatings from intoxicated strangers, abduction, or rape among other risks. It is also important they are inside when it rains so they don't get sick, caught in an accident, or get struck by lightning. Other adults also encourage children to return home after incidents like misbehavior or poor socializing with others. Children are also directed home to receive feedback or criticism from adults. Legitimate reasons for being inside the house include studying, praying, eating, conversing, resting, and watching television in rare case when a household has a TV.

In households with dirt floors, children spend much of their time studying, praying, eating, conversing, and resting outside the house on the veranda, under a tree, or in the kitchen typically a building with a dirt floor that is separate from the main house. Conversely, many participants reported that after improved floors were installed, children did many of these same activities inside, spending two to six additional hours inside. The immediate change in behavior may be a novelty effect:

> *[When the improved floor was first installed] they were very excited about playing inside the house, but nowadays they don't [play inside as much]* (Male, 60 years old, hh213183).

Similarly, several participants said that they spent one to four more hours inside the house after installing improved EarthEnable floors. Participants reported transitioning activities like eating, resting, and hosting visitors from outside to inside the house. One woman said that after the EarthEnable floor was installed in her house she started a small business in her home, so she now spends substantially more time inside. Another family reported that after installing improved flooring, all members of their family spend a substantial amount of time inside because they watch TV.

2.3.5 Changes in Well-Being Following Installation of Improved Flooring

After installing improved housing materials, participants experienced changes in their well-being, dignity, and status. Participants reportedly did not anticipate these changes, so they were not factors in initially deciding to construct with improved materials.

Overall well-being

The changes in their physical environment and the accompanying changes in their own behaviors contributed to participants feeling happier, more relaxed, more peaceful, more confident about their children's health, more comfortable hosting guests, and more respected after the improved floor was installed. Participants attributed their improved feelings to less dust (in spatial extent and amount) soiling their clothes, bodies, utensils, and other objects. In addition, participants linked their happiness to adults, children, and guests being able to sit and sleep well on the smooth floor, unmolested by pests. Participants were also less concerned that children might fall sick. They saw benefits from an improved sense of organization, and appreciated the compliments earned from visitors. One respondent reported, "[Now that I have an EarthEnable floor,] I am confident that my children are healthier. I feel [freer] now to host visitors because I have a place to host them. I feel so good being in my home; better than in the past" (Male, 43 years old, hh211221).

Dignity

Women shared they want their homes to give the impression that they are clean and responsible individuals, and conscious about their own health, the health of their children, and the comfort of their guests. To demonstrate their values, women sweep and mop the floor, clean their clothing and utensils, and organize the house. One respondent shared her cleaning schedule:

> *[I] start by sweeping my compound, such that no trash is seen in my compound. [If I don't clean then] I might have a female visitor who wants to be hosted in the house but if the house is dirty then I wouldn't feel like taking her inside. [Visitors] should see that all the clothes are clean and all utensils are clean and well organized on the rack. They should not find the chickens eating off the same utensils that people might use. If a visitor saw this, then she might ask herself, 'Are they going to serve me food from the same utensil that the chicken ate from?'* (Female, 38 years old, hh212125).

> *I want [visitors] to have the impression that I am health-minded, because [with installation of improved flooring] all the parasites and rats will stop disturbing and feasting on my children* (Female, 34 years old, hh14871)

Participants felt that constructing an improved floor helped create the clean and tidy impression they desire. Participants said that before the EarthEnable floor was installed, the dirt floors in their homes gave off an impression poverty and uncleanliness. One woman felt that her unimproved floor reflects that she is, "slightly clean[er compared to a bare dirt floor]" because she smears the floor with cow dung to smooth it and keep the dust down. However, an improved floor signaled that the participant was cleaner, healthier, and more deserving of respect than before. One male participant shared that having an improved floor in his home demonstrated that he was able to take care of his home.

Status

Several participants said that after constructing an improved floor, they moved to "another level of development." Some expressed desire to participate in other "development" programs. Participants defined "development" as inclusive of both economic and non-economic aspects of progression. One woman shared that installing an improved floor in her house demonstrates that she progressed in life:

> *In the past people used to talk about my house badly like, 'when you go to Suzan's house you all come out of her house when you all filled with dust…'Now people have realized that [I] am somewhere in life* (Female, 29 years old, hh11401).

Another participant said she felt more respected after installing the floor: "Nowadays I feel happier because people respect me because I made my floor" (Female, 32, hh211033). Similarly, one young man said, "I feel so confident nowadays to host a guest, I even host my girlfriend. She sees that I am on another level in development, so she respects me easily" (Male, 26 years old, hh212186).

Using more expensive and durable materials in the house structure is also a sign of an individual's economic status. Costly and hardy materials indicate that an individual has enough money to purchase material goods they desire. One woman expressed it as: "Whatever I want, I get it. I can't be jealous of anything because I get what I want" (Female, 38 years old, hh212125). Another man described how the elements of his house demonstrate his economic status:

I can show my level of [economic] development because when you look at my house, I put on nice doors with a nice floor, and the toilet that has all the necessary accessories, and when someone sees this he can say that there is development (Male, 26 years old, hh12676).

2.4 DISCUSSION

2.4.1 The Transformative Effect of Improved Flooring

Improved flooring transformed perceptions of dirt and dust among the households interviewed. Dust became widely understood as a nuisance overtime instead of a frustrating, but constant byproduct of a common housing material. Dirt has been defined as "matter out of place" (Douglas and Isherwood 1966). A useful concept is Douglas's "relativity of dirt," which refers to the positions of objects in the home determining what is "dirty" and what is not; a pertinent example is labeling shoes placed on a dining table as dirty, while when shoes are placed on the ground, they are not dirty (Jenkins 1999). Installing an improved roof, improved walls, or improved floors creates a space where dirt becomes "matter out of place." In contrast, dirt in a house with a dirt floor is not unclean, just as dirt outside the house is not unclean.

In the same way that a dirt floor made a dirty, disorganized environment the norm, an improved floor made cleanliness, and the associated organization, the standard. Replacing dirt floors with improved flooring brought order to the house. Both adults and children modified their behavior to match the cleanliness and organization they felt came with the improved floor. Not only did some participants report sweeping the floor more frequently, they also reported bathing more frequently, changing into new clothes after bathing, and removing their shoes before entering a room with an improved floor.

Men also organized their homes by assigning a specific purpose for each room and women organized objects in individual rooms. Not only did increased organization come with attention to objects already in the household, but increased organization also made it clear which objects were out of place. Participants reported that children stopped throwing trash on the floor and some participants also stopped allowing their domestic animals to sleep inside the house.

Improved flooring was not only enabling by allowing a task to be done more easily, but it was also motivating, encouraging the task through rapid positive feedback. Participants said that cleaning felt more worthwhile because women could observe the fruits of their labor immediately and the cleanliness lasted longer with improved flooring. Improved flooring made cleaning easier, so in many cases the same degree of cleanliness could be achieved with lower effort. For example, women who washed clothes four times per week started to wash clothes only three times per week after the improved floors were installed. Conversely, women who conceded to living in dirty clothes before installing improved floors became willing to launder their clothes once or twice per week. They knew their clean clothes would stay clean, even after sweeping or sitting on a surface in the home. Improved flooring also allowed households to maintain a higher level of cleanliness, which sometimes reduced total cleaning effort and sometimes made extra cleaning worthwhile. With improved floors, households reduced utensil washing to just once after use, instead of both before (to remove residue and dust) and after.

2.4.2 Personal and Societal Value of Cleanliness

The motivation for use of improved housing materials was both a "push" away from pest-ridden dirt and omnipresent dust that soiled every surface and a "pull" toward more beautiful, trendier materials. Participants reported feeling cleaner, happier, more relaxed, more peaceful, more confident about their

children's health, more comfortable hosting guests, and more respected after installing the improved floor. One woman commented, "when the visitors come around [to my house] and find it very clean, they feel at peace" (Female, 36 years old, hh212151).

Cleanliness occupies central importance in broader Ugandan society, as well as the Busoga society specifically. Isiko describes the Nile River as an important body of water for the Basoga who believe it has healing properties and consequently use the river in ritual body cleansing. The sick are expected to bathe in the river to rid themselves of illness and other bad luck. (Isiko 2019) In Mary Douglas' ethnographic studies of the cultural significance of dirt, she describes how compliance with ideas of purity and cleanliness is considered respectful of the way things ought to be and is associated with prosperity and good fortune. In contrast, dirt and feces are associated with misfortune and negative consequences. Thus, cultural beliefs and taboos regarding dirt and feces reflect certain societal and cultural norms (Douglas and Isherwood 1966). Perceptions of individual and household cleanliness may also affect moral judgements of individual or household behavior. Incidental feelings of disgust, associated with filth, make moral judgment more severe, while perceptions of cleanliness have the opposite effect (Schnall, Benton, and Harvey 2008). The perceived wrongdoings of those considered dirty may be harsher than for those who are considered clean.

Cleanliness is also associated with dignity, improved status, and the ability to care for oneself. Altered behaviors associated with the improved floors exemplify these cultural associations. For example, individuals modified their behaviors of self-care and home maintenance to match the cleanliness of the floor. Several women reported changing into clean clothes when they previously would have changed into used clothing, and while women and men reported improving the organization of their household items. In some cases, the improved floor lessened people's daily workload, freeing up valuable time to care for themselves and their families while providing them with a safer, more comfortable place to rest. Participants also reported increases in status and increased respect and admiration from the community.

2.4.3 Interaction Between Improve Flooring and Gender

Improved flooring reduced the difficulty and/or frequency of household cleaning, which is typically a burden borne by women in Uganda and worldwide. For example, sweeping no longer kicked up dust that would otherwise settle on utensils, bedsheets, and clothes. Less dust resident correlated with less laundering and cleaning. Some women increased their sweeping and mopping because of the visible and positive effect it has on the EarthEnable flooring. Additionally, after installing improved flooring, households disallowed their animals from entering the house, thereby reducing the work of cleaning animal feces and other dirt from the house. Future research could quantify the impact of improved flooring on the amount of time and perceived effort women spend cleaning their homes, in conjunction with perceived satisfaction and objective measurements of the loads of dust on floors. Other observations of gender-specific interactions with flooring are noted in the relevant sections throughout this report.

While participants reported largely positive changes in behaviors and perceptions associated with the floors overall, given the gendered nature of social norms and women's roles and responsibilities in cleaning, water-fetching, maintaining the home, and caregiving for children, future research should pay close attention to these shifts, and monitor for any associated benefits or negative consequences, specifically for women.

2.4.4 Limitations

The generalizability of study results may be limited by the relatively homogenous culture and region of the interviewees selected. Important information may also have been lost during concurrent summarizing and translation. The wording and order of questions may have biased responses, and responses may have been affected by participants feeling observed or judged. As shown in the responses, everyone wants to be perceived as clean. Interviews during a follow-up study would also be informative in determining whether participants maintain behaviors after becoming more accustomed to the improved floor, or whether old habits start to resurface when the floor is less of a novelty. Nonetheless, these interviews help us gain insight into individuals' preferences and behaviors.

2.4.5 Conclusions

Installation of improved flooring is a one-time investment with very low maintenance requirements. Our in-depth interviews suggest that improved flooring is not only an enabling technology, but it is also a motivating technology because people are motivated to conduct the behaviors that maintain the clean, smooth, aesthetically pleasing surface of the improved floor. These improved hygiene behaviors include frequently sweeping and mopping; removing shoes before entering rooms; prohibiting domestic animals from entering or sleeping in the room. Such behaviors would reduce the amount of dirt and fecal matter tracked into the house or generated in the house and increase the amount of dirt and fecal matter removed from the house. Participants reported self-initiated and sustained changes in personal and household hygiene and organization associated with installation of improved flooring. This suggests that improved flooring may benefit child health both through covering up the dirt where pests live as well as through the behaviors enabled and motivated by the new infrastructure. Building on this complementarity may open new doors for reducing environmental health risks.

3.0 PART 2. HAND- AND OBJECT-MOUTHING AMONG CHILDREN AND PREGNANT WOMEN IN RURAL EASTERN UGANDA

3.1 INTRODUCTION

Exposure factors, such as an individual's mass, surface area, food consumption, time spent in certain locations, and frequency of mouthing hands and objects, determine how much an individual is exposed to an environmental contaminant (U.S. Environmental Protection Agency 2011). Studies evaluating environmental health risks of unborn and young children in low-and-middle income countries have relied on exposure data from the United States or high-income countries, from which data on exposure factor is more readily available (Mattioli, Davis, and Boehm 2015; Wang et al. 2017). However, if individuals in low-income countries and/or low-income settings have different exposure factors than individuals in high-income settings, then utilizing exposure factor data from high-income countries to model health risks may over- or underestimate risks for individuals in low-income countries. Quantifying the exposure factors of children and pregnant women is a particularly valuable project because children and unborn fetuses are more sensitive to environmental health risks than other individuals; young and unborn children have a relatively high surface area to volume ratio (U.S. Environmental Protection Agency 2011).

Children in low-income countries may also be at higher risk of exposure to contaminants in the environment because of weak or non-existent government standards and/or regulations allowing contaminant release into the environment. For example, informal lead-acid battery recycling and artisanal gold mining can contaminate the environment with heavy metals (Haefliger et al. 2009) while uncontrolled application of unregulated pesticides can contaminate the environment with persistent organic pollutants (Agency for Toxic Substance and Disease Registry 2002; Cantu-Soto et al. 2011). Cooking with biomass fuels can create indoor air pollution (Smith 2000). Children may also be exposed to contaminants that are more difficult for low-resource communities to manage. For example, children and pregnant women may be exposed to soil-transmitted helminths (Aderoba et al. 2015; Adriko et al. 2018), arsenic in water (Mukherjee et al. 2006), or mycotoxins in food (Bankole, Schollenberger, and Drochner 2006) all of which require improved infrastructure and financial resources to detect and mitigate.

Few studies have characterized exposure factors for children in low-income countries. These include studies in Bangladesh (Kwong et al. 2019; Kwong, Ercumen, Pickering, Unicomb, et al. 2020), Haiti (Medgyesi et al. 2018), Zimbabwe (Ngure et al. 2013), and Ghana (Teunis et al. 2016). In Zimbabwe, for example, 23 children less than 18 months old were observed for exposure factors over a six-hour period. Staff recorded activities like mouthing food and water; mouthing utensils including their own, their siblings', and their mother's hands; mouthing their mother's breasts, soil, stones, and chicken feces (Ngure et al. 2013). In Ghana, 154 urban children 0-5 years old were observed for two to three hours. Researchers collecting information on activities like playing/sitting, sleeping, hand washing, bathing, defecating, or eating; along with the child's location (Teunis et al. 2016). Exposure factors studies among

adults in low-income studies are rare, and have focused on geophagia among pregnant women (Luoba et al. 2005).

To increase the very limited knowledge on exposure factors among children and pregnant women in low-income countries, EarthEnable conducted observations of young children and pregnant women in rural Uganda to quantify exposure factors including hand- and object-mouthing frequencies, prevalence and frequency of direct soil ingestion, and time spent indoors. The observed populations were split into two groups (study arms): homes with some improved flooring (the treatment group) and those who lived in homes with no improved flooring (the control group).

Reductions in soil-transmitted helminth infections have been associated with improved flooring (Benjamin-Chung et al. 2021). One way to reduce exposure to soil and soil-borne pathogens is to replace natural or rudimentary floors (collectively called "unimproved" floors) with finished ("improved") floors. USAID's demographic and health surveys define natural floors as those made of earth, sand, clay, or dung and rudimentary floors are made of wood planks, palm, bamboo, mats, or adobe. Finished floors are those made of stone, brick, ceramic, polished wood, vinyl, linoleum, or carpet (Florey and Taylor 2016). Given the link between flooring and disease transmission, the research team also examined relationships (if any) between where children spend time (indoors vs. outdoors and on improved vs. unimproved flooring) with changes to children's mouthing behaviors.

3.2 METHODS

3.2.1 Observations of Children

The study sought to recruit 20 children from each of the following age groups: less than 6, 6-11, 12-17, 18-23, 24-35, 36-47, and 48-59 months old. These groups were selected based the U.S. Environmental Protection Agency's guidance on age groups for health risk assessment (U.S. Environmental Protection Agency 2005). The team planned for 10 children in each age group to be from homes with no improved flooring (i.e., 100 percent earthen flooring) and 10 children in each age group to be from homes with more than 50 percent improved flooring. The team selected an even number of girls and boys in each age group. We expected that household members present during the day (primarily women and children) would be more comfortable with a female observer than a male observer, so we trained females from local village health teams (VHTs) to video record the observations.

Daytime observations. The field manager trained VHTs to use a video camera to record children's activities at their homes for six hours during the daytime. The start time varied from 7:30 am to 1:00 pm to capture variation in household and child activities. Observations were spread across all days of the week. Observers did not record while the focus child was sleeping or using a latrine. To assess short-term variability in mouthing behavior, children were observed on two separate occasions within 10 days. To assess the correlation between the two methods of quantifying mouthing events captured in video recordings (and later coded) and mouthing recorded in real-time, a subset of observations that were video recorded were simultaneously recorded in real-time and compared.

Evening observations. The research team also conducted observations of children during the evening. Trained observation coding staff conducted these observations in real-time. Video recordings were not made during the evening because homes were too dark for the video to capture the scene. The team chose not to artificially light the room because doing so would disrupt household members' normal

behavior. The subset of children who participated in the real-time and evening observations were randomly selected.

3.2.2 Observations of Pregnant Women

The research team sought to recruit 20 pregnant women. Of these, the team planned for 10 women from homes with no improved flooring (100 percent dirt flooring) and 10 women to be from homes with more than 50 percent improved flooring.

Daytime observations. Local VHT members were trained to use a video camera to record the activities of pregnant women at their homes for six hours during the daytime. The start time varied from 8:00 am to 1:00 pm to capture variation in household and women's activities. Observations were spread across all days of the week. Observers did not record while the selected woman was sleeping or using a latrine.

3.2.3 Recording Behaviors

Trained staff coded video recordings and live observations using the tablet-based LiveTrak application. LiveTrak allowed coders to record hand-to-mouth and object-to-mouth contacts, as well as the child's activity (e.g., playing, eating, bathing, handwashing, urinating, defecating), the surface on which the child stood/sat/laid, the child's location, the amount of clothing worn by the child, whether the child was wearing shoes, and details about the caregiver's activities (Figure 1). LiveTrak was used to record each individual contact: if the child put an object in her mouth, took it out, and put it back in her mouth this was recorded as two separate contacts with the object. There was no minimum duration required between contacts with the same object to record them as separate contacts. An instance in which a child's hand or a utensil contacted the child's mouth while placing an object in the mouth counted as one hand-to-mouth and one object-to-mouth contact. Items were grouped into several categories: any individual's hands or skin (other than breasts), breasts, solid foods, liquid foods, soil and ash, human and animal feces, and other types of objects (e.g., plastic, paper, and metal).

Figure 1: Pallet in LiveTrak app used to record details of observations. The top panel displays the screen that allows the observer to record what items are put into the child's mouth, what surface the child is on, the child's stance, the child's general activity, whether the child is wearing shoes, and the presence of animals in the scene.

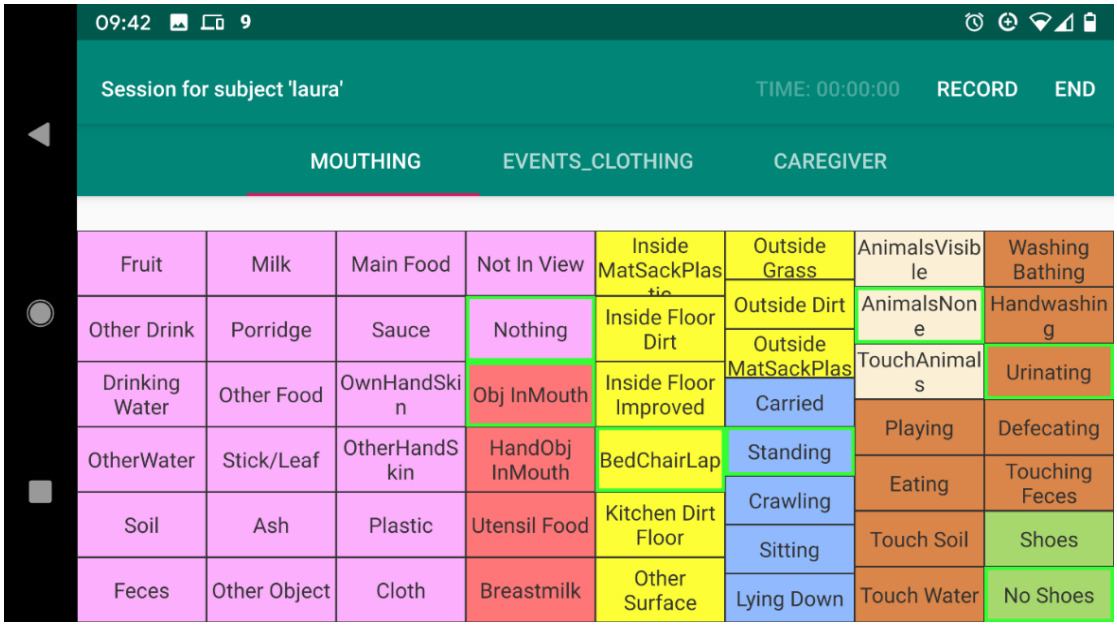


Figure 1. Panel to record mouthing activity

Figure 2: This panel displays the screen that allows the observer to record the degree to which the child is clothed.

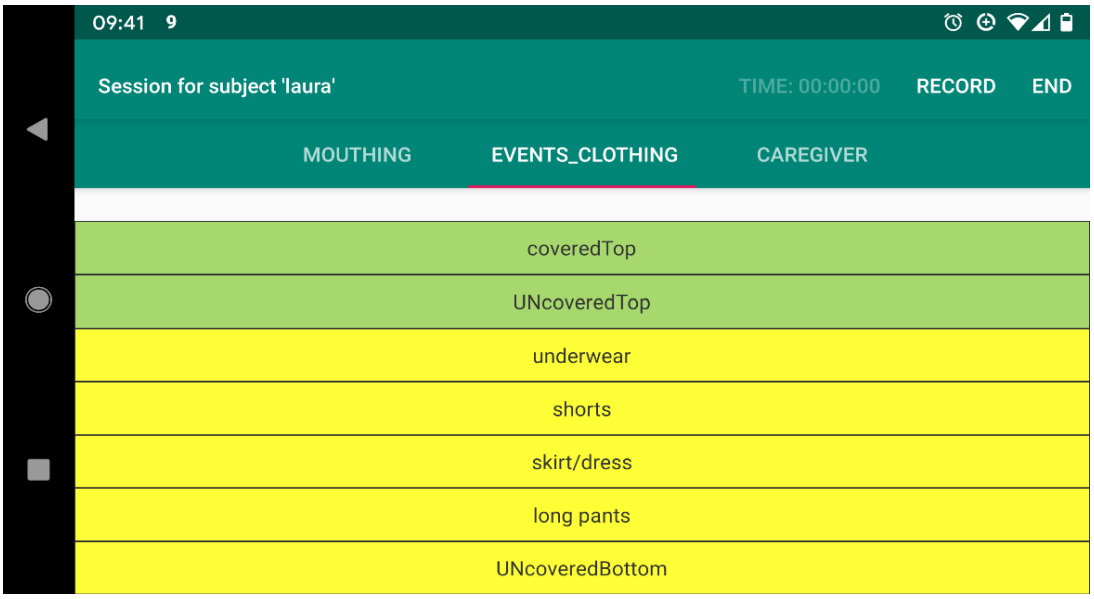


Figure 2. Degree to which child is clothed

Figure 3: This panel displays the screen that allows the observer to record who is caring for the child and other activities that the person is engaged in while caring for the child.

Figure 3. Caregiver's activities

3.2.4 Statistical analyses

Descriptive statistics

The research team calculated descriptive statistics separately for data generated through 1) coding videos conducted during the day, 2) daytime real-time ("live") coding and 3) evening real-time coding; and separately for children and pregnant women. To compare the data with existing data, the study sometimes presents descriptive statistics for children in different age groups, locations, or study arm, even when the differences between the groups are not statistically different. Descriptive statistics treat each observation as a unique data point; the study does not weight observations or consider that some children contributed more observations than others. The study assumes that if a child is recorded as sitting on a bed, chair, or lap, or an "other (elevated) surface," their indoor or outdoor location did not change. The research team reports frequencies for all children who were observed engaging in the behavior. Children who were not observed engaging in the behavior are excluded from the frequency calculation.

Inter-rater reliability

To measure inter-rater reliability, the research team analyzed clips that all coders coded to calculate the intraclass correlation (ICC) (McGraw 1996). The team tasked four coders with observing children and two coders with observing pregnant women. The single score intraclass correlation applies when a subset of subjects is coded by multiple raters and the reliability of their ratings is meant to generalize to the subjects rated by a single coder. The average score intraclass correlation applies when all subjects are coded by multiple raters and the average of the ratings is used for hypothesis testing. We report both as is recommended if there is a discrepancy between the single-measures and average-measures

result. The inter-rater reliability accounted for the round of observation, household, clip, and type of mouthing event (class of object mouthed). Staff did not begin translating the videos until after they could watch the same video and reliably code a similar number of each of a set of behaviors (achieving high intercoder reliability, as indicated by an intraclass correlation of greater than 0.75).

Differences by study arm, age group, and type of object

The research team used linear mixed models to assess differences in mouthing frequencies and the amount of time spent on different flooring types by study arm or age group, controlling for the type of object mouthed. The random effect was used to account for repeated observations of the same child.

Association between coded video data and real-time observation

The research team assessed the association between coded video data and real-time observation using Pearson's correlation coefficient, which measures the strength of the linear relationship between two variables .

3.2.5 Ethics

Pregnant women and caregivers of participating children provided informed written consent before the observation. The study was conducted in accordance with the Declaration of Helsinki (the international statement of ethical principles for medical research involving human subjects) and received ethical approval from Makerere University (SBS-730).

3.3 RESULTS AND DISCUSSION

3.3.1 Number and duration of observations

A total of 122 unique children from 116 households were observed and video recorded; due to errors in the field, some households had two children who were observed on different days. 51 percent of observed children were female. 122 unique children were observed during the day on one occasion, 74 children were observed twice, and 27 children were observed three times, for a total of 223 days of child observations by video. Some children were observed only once because they refused a follow-up observation. Some children were observed three times because more than 10 days passed between their first and second observations. A total of 48 children were observed in real-time during the daytime, while 20 children were observed in real-time in the evening. Daytime observations of children were a mean of 4 hours and 45 minutes (a standard deviation of 1 hour and 2 minutes) while evening observations were a mean of 4 hours and 19 minutes (a standard deviation of 26 minutes).

The team observed and video-recorded 22 unique women from 22 households. A total of 22 women were observed once, and 21 were observed twice. Daytime observations of pregnant women were a mean of 4 hours and 43 minutes.

Table 1: Number of participants observed using each method

			Number of children observed		
Demographic	Age group	Arm	Daytime, video	Daytime, live	Evening, live
child	<6 months	improved	11	3	2
child	<6 months	unimproved	13	2	0

			Number of children observed		
Demographic	Age group	Arm	Daytime, video	Daytime, live	Evening, live
child	6-11 months	improved	17	2	1
child	6-11 months	unimproved	35	8	3
child	12-17 months	improved	25	5	2
child	12-17 months	unimproved	24	8	4
child	18-23 months	improved	21	8	2
child	18-23 months	unimproved	22	7	2
child	24-35 months	improved	13	1	0
child	24-35 months	unimproved	13	2	1
child	36-47 months	improved	6	1	1
child	36-47 months	unimproved	11	2	0
child	48-59 months	improved	7	0	1
child	48-59 months	unimproved	5	1	1
pregnant woman	child-bearing age	improved	19	0	0
pregnant woman	child-bearing age	unimproved	24	0	0

3.3.2 Inter-rater Reliability

For the child observations, the two-way mixed, consistency, single-measure ICC was 0.76 while the average-measure ICC was 0.93. The figure indicates that the agreement between coders ranged from good (0.60-0.749) to excellent (0.75-1.00) (Cicchetti 1994) and that there was a minimal amount of measurement error introduced by independent coders, preserving statistical power for comparative analyses. An insufficient number of observations of pregnant women were coded two or more times to compute a precise ICC, but the study team infers it would be similar to that of child observations given similar procedures were followed for observations of both type of participants.

3.3.3 Mouthing frequencies among young children

Considering all age groups combined, children mouthed hands a median 31.3 times/hour, put objects in their mouths 8.7 times/hour, put food in their mouth 37.2 times/hour, a drank liquids 6.1 times/hour. A total of 76 children (34%) were observed putting soil or ash in their mouths, with a median of 0.7 times/hour, and 16 children (7%) were observed putting feces in their mouths, with a median of 0.2 times/hour.

Table 2: Mouthing frequencies among young children in rural Uganda, with all ages combined

		Mouthing frequency (times/hr)				
Object in mouth	Mouthers (n)	Mean	Sd	Median	Min	Max
Hands	222	34.2	21.6	29.7	0.8	137.2
Objects	220	12.3	12.3	8.1	0.2	71.1
Foods	212	44.3	29.8	37.2	0.2	192.9
Liquids	201	8.5	7.6	6.1	0.2	44.1

		Mouthing frequency (times/hr)				
Object in mouth	**Mouthers (n)**	**Mean**	**Sd**	**Median**	**Min**	**Max**
Soil or ash	76	1.3	1.8	0.7	0.1	11.1
Feces	16	0.6	1.3	0.2	0.2	5.3
Breasts	107	12.2	12.7	8.7	0.2	79.3

Mouthing frequency and age

Controlling for the type of object mouthed, there was also no significant association between mouthing frequencies and age group (p=0.43). Younger children were significantly more likely to breastfeed (p=0.0002). The relationship between age groups and mouthing frequencies is shown in Figure 4.

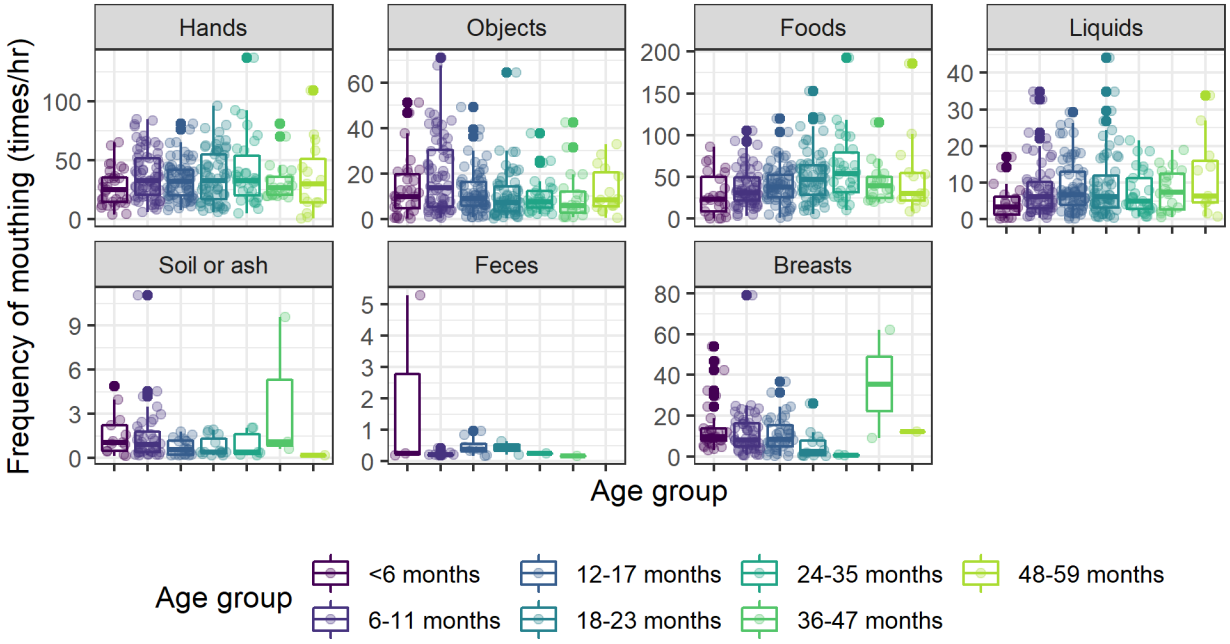


Figure 4. Frequency of hand- and object-mouthing among young children in rural Uganda, by age group

Among children in this study, median hand mouthing frequency was 33 times per hour for children 6-11 months old, 33 times per hour for children 12-17 months old, 33 times per hour for children 12–23 months old, 33 times per hour for children 24–35 months old, 27 times hour for children 36–47 months old, and 30 times per hour for children 48-59 months old (Table 3).

In contrast, among children in Bangladesh, median hand mouthing frequency was 43 times per hour for children 6-11 months old, 47 times per hour for children 12–23 months old, 51 times per hour for children 24–35 months old, and 72 times per hour for children 36–47 months old (Kwong, Ercumen, Pickering, Unicomb, et al. 2020).

In the U.S., median outdoor hand mouthing was 11 times per hour for children 6-11 months old, 8 times per hour for children 12-24 months old, 3 times per hour for children 24-35 months old, 6 times per hour for children 36-71 months old. Indoor hand mouthing frequencies among children in the U.S. are

approximately twice as high as outdoor mouthing (Xue et al. 2007), resulting in all indoor and outdoor hand mouthing frequency estimates being less than those for children in rural Uganda.

Table 3: Mouthing frequencies among young children in rural Uganda, by age

			Mouthing frequency (times/hr)				
Age group	**Object in mouth**	**N**	**Mean**	**Sd**	**Median**	**Min**	**Max**
<6 months	Hands	31	27.4	15.9	25.2	4.1	65.2
<6 months	Objects	30	13.6	13.0	9.9	0.2	51.2
<6 months	Foods	24	29.5	25.3	23.6	0.2	86.1
<6 months	Liquids	19	4.8	4.7	3.3	0.2	17.0
<6 months	Soil or ash	13	1.6	1.5	1.1	0.1	4.9
<6 months	Feces	3	1.9	2.9	0.2	0.2	5.3
<6 months	Breasts	29	15.0	13.4	9.7	2.9	54.0
6-11 months	Hands	66	37.8	20.5	32.7	6.1	84.8
6-11 months	Objects	66	19.2	16.6	13.9	0.4	71.1
6-11 months	Foods	65	37.4	22.8	30.7	2.9	105.0
6-11 months	Liquids	62	8.5	7.9	6.2	0.5	34.8
6-11 months	Soil or ash	37	1.5	2.0	0.9	0.2	11.1
6-11 months	Feces	9	0.2	0.1	0.2	0.2	0.4
6-11 months	Breasts	55	11.5	11.7	8.1	0.4	79.3
12-17 months	Hands	68	33.4	16.0	32.5	7.9	81.0
12-17 months	Objects	68	11.7	9.5	9.0	0.8	49.4
12-17 months	Foods	68	41.0	22.8	37.7	0.7	120.1
12-17 months	Liquids	67	9.0	7.2	6.7	0.2	29.2
12-17 months	Soil or ash	20	0.7	0.5	0.6	0.2	1.8
12-17 months	Feces	8	0.5	0.3	0.4	0.2	1.0
12-17 months	Breasts	40	10.6	8.4	8.5	0.2	36.7
18-23 months	Hands	62	36.3	21.9	32.7	6.3	96.4
18-23 months	Objects	62	10.2	10.4	7.4	0.2	64.6
18-23 months	Foods	61	51.0	30.5	47.1	5.7	153.0
18-23 months	Liquids	59	9.4	9.2	6.1	0.4	44.1
18-23 months	Soil or ash	15	0.8	0.7	0.4	0.2	1.9
18-23 months	Feces	2	0.4	0.3	0.4	0.2	0.6

			Mouthing frequency (times/hr)				
Age group	Object in mouth	N	Mean	Sd	Median	Min	Max
18-23 months	Breasts	12	5.7	7.6	2.4	0.2	26.1
24-35 months	Hands	30	40.9	29.6	33.0	4.9	137.2
24-35 months	Objects	30	9.9	7.9	7.6	2.3	37.7
24-35 months	Foods	30	59.6	39.0	54.2	10.3	192.9
24-35 months	Liquids	29	7.2	5.9	5.0	0.7	21.5
24-35 months	Soil or ash	6	0.9	0.9	0.4	0.2	2.0
24-35 months	Feces	1	0.2	NA	0.2	0.2	0.2
24-35 months	Breasts	2	0.6	0.3	0.6	0.4	0.8
36-47 months	Hands	20	32.3	17.0	26.9	18.8	81.1
36-47 months	Objects	19	10.0	11.3	5.8	0.8	42.6
36-47 months	Foods	19	43.3	23.0	39.2	20.5	115.3
36-47 months	Liquids	19	8.1	5.5	7.4	0.6	18.9
36-47 months	Soil or ash	3	3.8	5.1	1.1	0.6	9.6
36-47 months	Feces	1	0.2	NA	0.2	0.2	0.2
36-47 months	Breasts	2	35.5	37.6	35.5	8.9	62.1
48-59 months	Hands	15	34.9	30.9	30.3	0.8	109.5
48-59 months	Objects	15	12.5	10.2	8.5	0.4	32.9
48-59 months	Foods	14	49.7	47.0	30.0	9.0	186.0
48-59 months	Liquids	11	11.7	10.7	6.3	0.7	33.7
48-59 months	Soil or ash	1	0.2	NA	0.2	0.2	0.2
48-59 months	Breasts	1	12.2	NA	12.2	12.2	12.2

3.3.4 Mouthing Frequencies Among Pregnant Women

Pregnant women put hands in their mouths a median of 5.4 times per hour, put objects in their mouths 2.1 times per hour, consumed food 22.6 times per hour (mouthfuls), and drank liquid 4.8 times per hour. Five women were observed putting soil or ash in their mouths, with an average of 0.8 times per hour (Figure 5, Table 4). There is very little literature on the mouthing frequencies of adults other than occupational settings (Sklar et al. 2019; Gorman Ng et al. 2016).

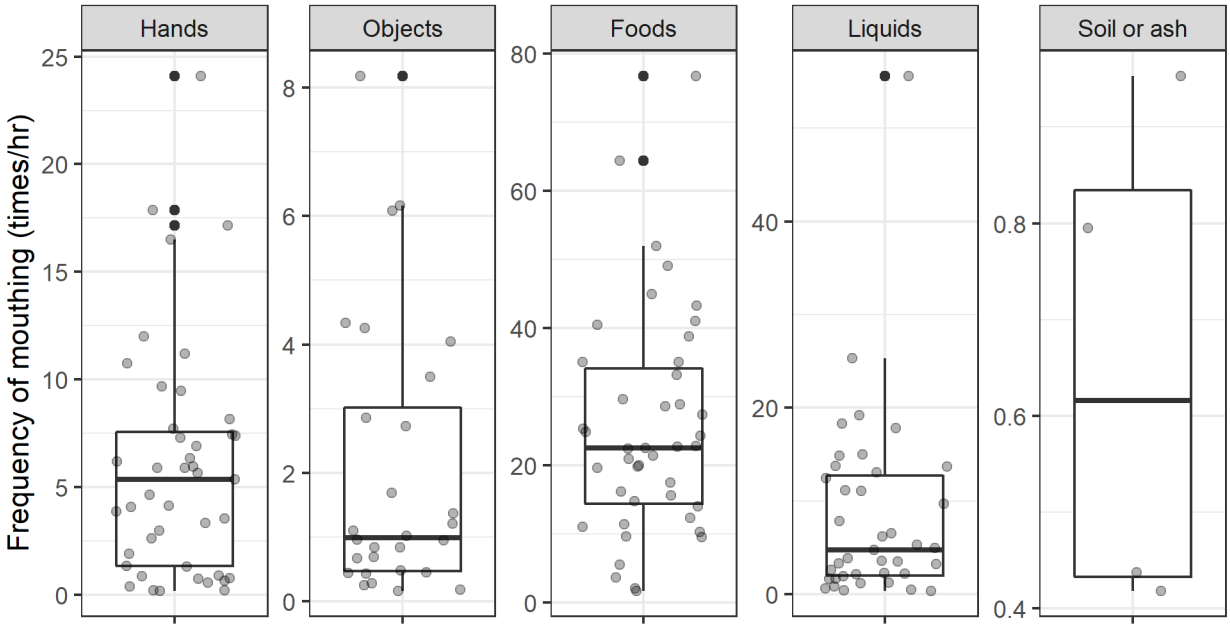


Figure 5. Frequency of hand- and object-mouthing among pregnant women in rural Uganda. No women were observed mouthing feces.

Table 4: Mouthing frequencies among pregnant women in rural Uganda. No women were observed mouthing feces

		Mouthing frequency (times/hr)				
Object in mouth	**N**	**Mean**	**Sd**	**Median**	**Min**	**Max**
Hands	43	5.9	5.4	5.4	0.2	24.1
Objects	28	2.0	2.1	1.0	0.2	8.2
Foods	43	25.4	16.2	22.6	1.7	76.7
Liquids	39	8.3	10.1	4.8	0.4	55.6
Soil or ash	4	0.7	0.3	0.6	0.4	1.0

3.3.5 Percent of Time Spent Inside and Outside

Children spend most of their time outside. During the daytime observation, children spent an average of 84 percent of their observed time outdoors (Figure 6). One-third (30%) of children never went inside during the daytime observation while 3 percent were entirely inside and never ventured outside during the observation (Table 5). The percent of time children spent outside was associated with their age group ($p<0.001$) but not with the presence of improved flooring ($p=0.62$). Study observations contrast with reports from caregivers which state that children spend two to six additional hours inside after the installation of improved floors. This may be because children who spend additional time inside are older

than the children observed in this study. Alternatively, the additional time spent inside is partly due to the initial novelty of the floor and which fades over time.

In the evening, children were outside an average of 78 percent of their observed time (data not shown). In contrast, similar-aged children in Bangladesh spent 54 percent of their observed daytime hours outdoors (Kwong, Ercumen, Pickering, Unicomb, et al. 2020). Observations in Uganda and Bangladesh were conducted during the dry season; information collected during the qualitative interviews suggests that children may spend more time inside during the rainy season because children are instructed to stay inside during heavy rains.

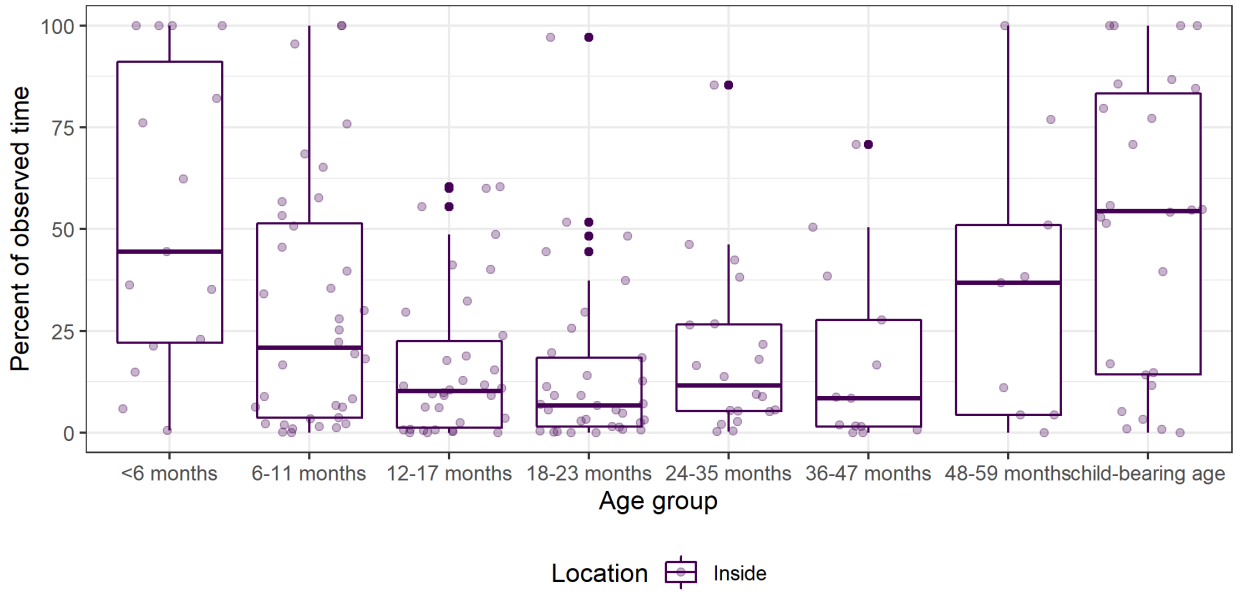


Figure 6. Percentage of day spend inside among young children in rural Uganda

Table 5: Percentage of children exclusively outside or inside during a 6-hour daytime observation of young children in rural Uganda

age group	total observations	always outside (#)	always outside (%)	always inside (#)	always inside (%)
<6 months	24	9	38%	4	17%
6-11 months	52	16	31%	2	4%
12-17 months	49	16	33%	0	0%
18-23 months	43	12	28%	0	0%
24-35 months	26	6	23%	0	0%
36-47 months	17	5	29%	0	0%
48-59 months	12	3	25%	1	8%
all children	**223**	**67**	**30%**	**7**	**3%**
child-bearing age	**43**	**18**	**42%**	**4**	**9%**

3.3.6 Mouthing by Inside/Outside Location

Controlling for type of object mouthed, mouthing rates were observed to be significantly lower when children were inside as opposed to outside ($p<0.0001$). Mouthing rates did not vary by age group ($p=0.55$). This is visible in the boxplots in Figure 7, with additional detail in Table 6.

In Bangladesh mouthing frequencies were not significantly different in inside versus outside locations (Kwong, Ercumen, Pickering, Unicomb, et al. 2020). However, in the U.S., hand and object mouthing are up to twice as high inside as compared to outside. The U.S., trends might be associated with the higher availability of toys inside; when they mouth these objects, they also mouth their hands (Xue et al. 2007; 2010). Compared to homes Bangladesh, which have a per capita GDP that is three times higher than Uganda ($1.7K vs $643; https://georank.org/economy/bangladesh/uganda), homes in rural Uganda have relatively few items, so it is possible that more of the items a child plays with and explores are outside.

Figure 7. Frequency of hand- and object-mouthing among young children in rural Uganda, by location

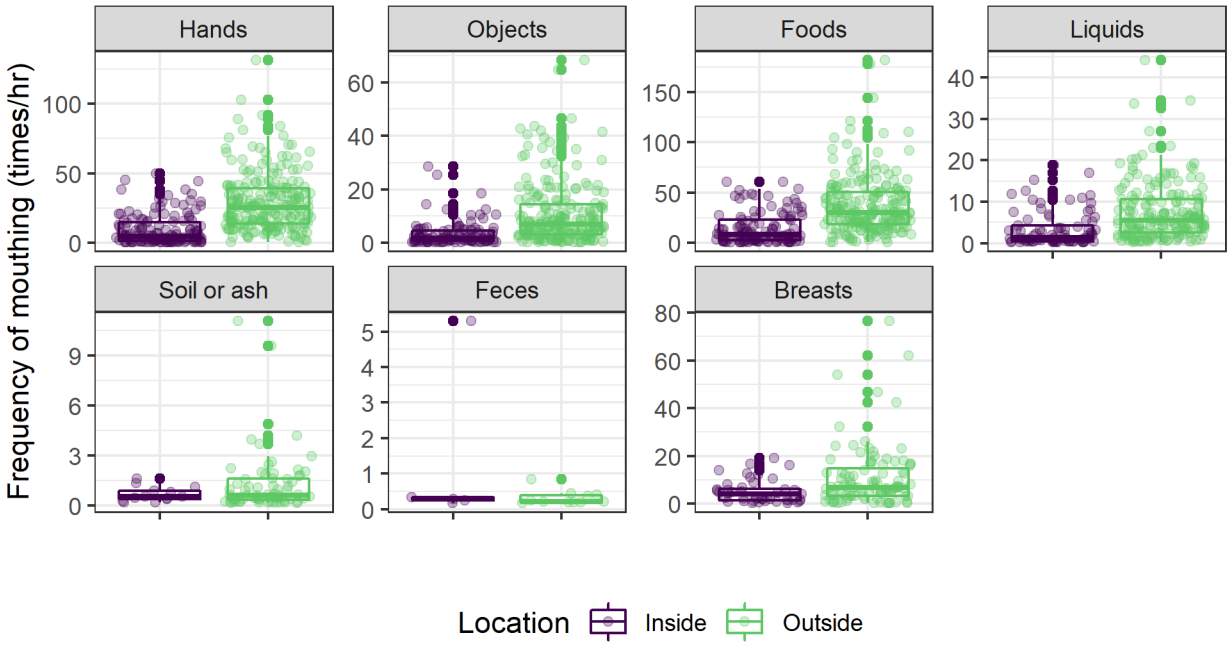


Table 6: Mouthing frequencies among young children in rural Uganda, by location

		Mouthing frequency (times/hr)					
Object in mouth	**Location**	**N**	**Mean**	**Sd**	**Median**	**Min**	**Max**
Hands	Inside	191	9.4	11.0	4.7	0.2	50.0
Hands	Outside	284	29.8	20.4	25.7	0.4	131.3
Objects	Inside	153	3.7	5.6	1.8	0.1	39.0
Objects	Outside	282	11.4	11.8	7.5	0.2	68.2
Foods	Inside	155	13.8	15.2	7.2	0.2	60.7
Foods	Outside	275	37.1	28.5	30.1	0.2	182.0
Liquids	Inside	113	3.5	4.4	1.4	0.2	20.5
Liquids	Outside	247	7.6	7.2	5.5	0.2	44.1
Soil or ash	Inside	14	0.6	0.5	0.5	0.2	1.6

		Mouthing frequency (times/hr)					
Object in mouth	**Location**	**N**	**Mean**	**Sd**	**Median**	**Min**	**Max**
Soil or ash	Outside	88	1.3	1.7	0.6	0.1	11.1
Feces	Inside	5	1.3	2.3	0.3	0.2	5.3
Feces	Outside	19	0.3	0.2	0.2	0.2	1.0
Breasts	Inside	56	5.3	4.9	3.8	0.2	19.0
Breasts	Outside	131	10.3	11.9	6.6	0.2	76.5

In contrast, controlling for type of object mouthed, mouthing rates did not differ significantly by inside or outside location among pregnant women ($p<0.22$). This is visible in the boxplots in Figure 8, with additional detail in Table 7.

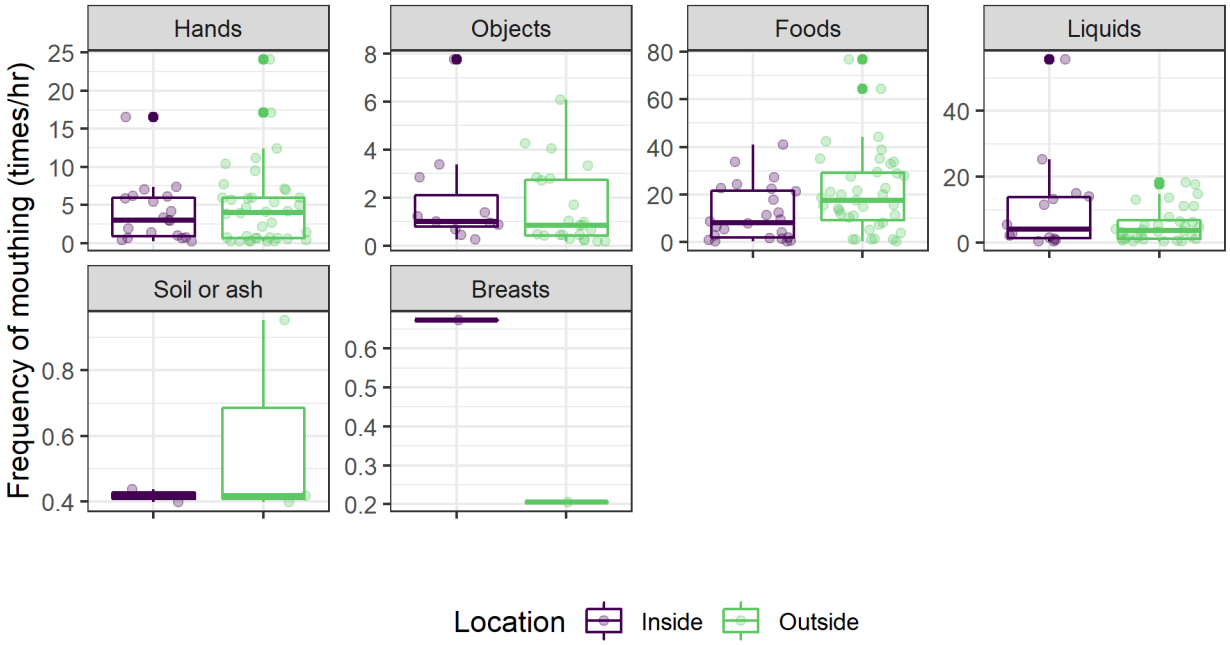


Figure 8. Frequency of hand- and object-mouthing among pregnant women in rural Uganda, by location

Table 7. Mouthing frequencies among pregnant women in rural Uganda, by location

		Mouthing frequency (times/hr)					
Object in mouth	**Location**	**N**	**Mean**	**Sd**	**Median**	**Min**	**Max**
Hands	Inside	19	3.9	3.9	3.0	0.2	16.5
Hands	Outside	38	4.7	5.2	4.0	0.2	24.1
Objects	Inside	11	1.9	2.2	1.0	0.3	7.8
Objects	Outside	23	1.5	1.6	0.8	0.2	6.1
Foods	Inside	24	11.9	11.7	8.1	0.2	41.1
Foods	Outside	39	20.7	17.1	17.5	0.2	76.7
Liquids	Inside	14	10.7	14.9	4.1	0.4	55.6
Liquids	Outside	32	5.4	5.3	3.7	0.4	18.3
Soil or ash	Inside	2	0.4	0.0	0.4	0.4	0.4
Soil or ash	Outside	3	0.6	0.3	0.4	0.4	1.0

Breasts	Inside	1	0.7	NA	0.7	0.7	0.7
Breasts	Outside	1	0.2	NA	0.2	0.2	0.2

3.3.7 Mouthing Frequencies by Inside/Outside Location and Study Arm

Controlling for type of object mouthed, there was no significant difference in mouthing frequencies between those children that lived in homes with some improved flooring (the treatment group) and those who lived in homes with no improved flooring (the control group) (p=0.78). When the effect of location and study arm was evaluated, location significantly impacted mouthing frequencies (p<0.0001) while study arm had no significant impact (p<0.81) (Figure 9).

The study scope does not include an analysis of hand- and object-mouthing frequencies by mothers, but the researchers did not observe any significant difference among those who lived in homes with improved flooring and those who lived in homes with no improved flooring.

3.3.8 Mouthing Soil and Feces

Nearly half (42%) of children less than 6 months old and nearly two-thirds (60%) of children 6-11 months old were observed mouthing soil; they mouthed soil approximately 1.6 times per hour. One-quarter to one-third of children 12-47 months old were also observed mouthing soil during the six-hour observation. Over 10 percent of children less than 11 months old mouthed feces during the observation, 2-8 percent of children 12-47 months old also mouthed feces. About 10 percent of pregnant women also mouthed soil, and no mothers mouthed feces (Table 8).

The prevalence of mouthing observed among children in rural Uganda was substantially higher than has been observed for young children in Bangladesh (Kwong, Ercumen, Pickering, Unicomb, et al. 2020), Zimbabwe (Ngure et al. 2013), and Ghana (Teunis et al. 2016). In those countries, for age groups with

more than five individuals, the prevalence of mouthing soil ranged from 10 to14 percent among children 3-5 months old; 0 to 42 percent for children 6-11 months old; 18 to 38 percent for children 12-23 months old, and 3 to 8 percent for children 24-47 months old.

Table 8. Prevalence and frequency of mouthing soil and feces, among young children and pregnant women in rural Uganda, by age group

Object	Age group	Total individuals	Mouthers (n)	Mouthers (%)	Mean frequency per individual (times/hr)
Soil or ash	<6 months	24	10	41.7	1.7
Soil or ash	6-11 months	52	31	59.6	1.6
Soil or ash	12-17 months	49	16	32.7	0.6
Soil or ash	18-23 months	43	10	23.3	0.8
Soil or ash	24-35 months	26	5	19.2	1.0
Soil or ash	36-47 months	17	3	17.6	3.8
Soil or ash	48-59 months	12	1	8.3	0.2
Soil or ash	child-bearing age	43	4	9.3	0.7
Feces	<6 months	24	3	12.5	1.9
Feces	6-11 months	52	6	11.5	0.2
Feces	12-17 months	49	4	8.2	0.5
Feces	18-23 months	43	1	2.3	0.2
Feces	24-35 months	26	1	3.8	0.2
Feces	36-47 months	17	1	5.9	0.2
Feces	48-59 months	12	0	0.0	NA
Feces	child-bearing age	43	0	0.0	NA

It was more common for children to put soil in their mouths when they were outside rather than inside; 8 percent of children mouthed soil while inside compared to 32 percent who mouthed soil while outside (Table 9).

Table 9. Prevalence and frequency of mouthing soil and feces, among young children in rural Uganda

Object	Total individuals	Mouthers (n)	Mouthers (%)	Mean frequency per individual (times/hr)
Soil or ash	160	13	8.1	0.7
Soil or ash	216	69	31.9	1.3
Feces	160	5	3.1	1.3
Feces	216	11	5.1	0.3

3.3.9 Day-to-day Variation in Mouthing Frequencies

Day-to-day variation among children

The Pearson correlation coefficient for observations of the same child conducted within 10 days was 0.27 for hand mouthing, 0.36 for object mouthing, 0.40 for soil mouthing, -0.28 for feces mouthing, 0.35 for putting food in the mouth, and 0.15 for putting liquid in the mouth (Figure 10). This degree of

correlation is low, indicating that day-to-day variation is high and that mouthing data from a child captured on any given day does not reflect mouthing data on any other day.

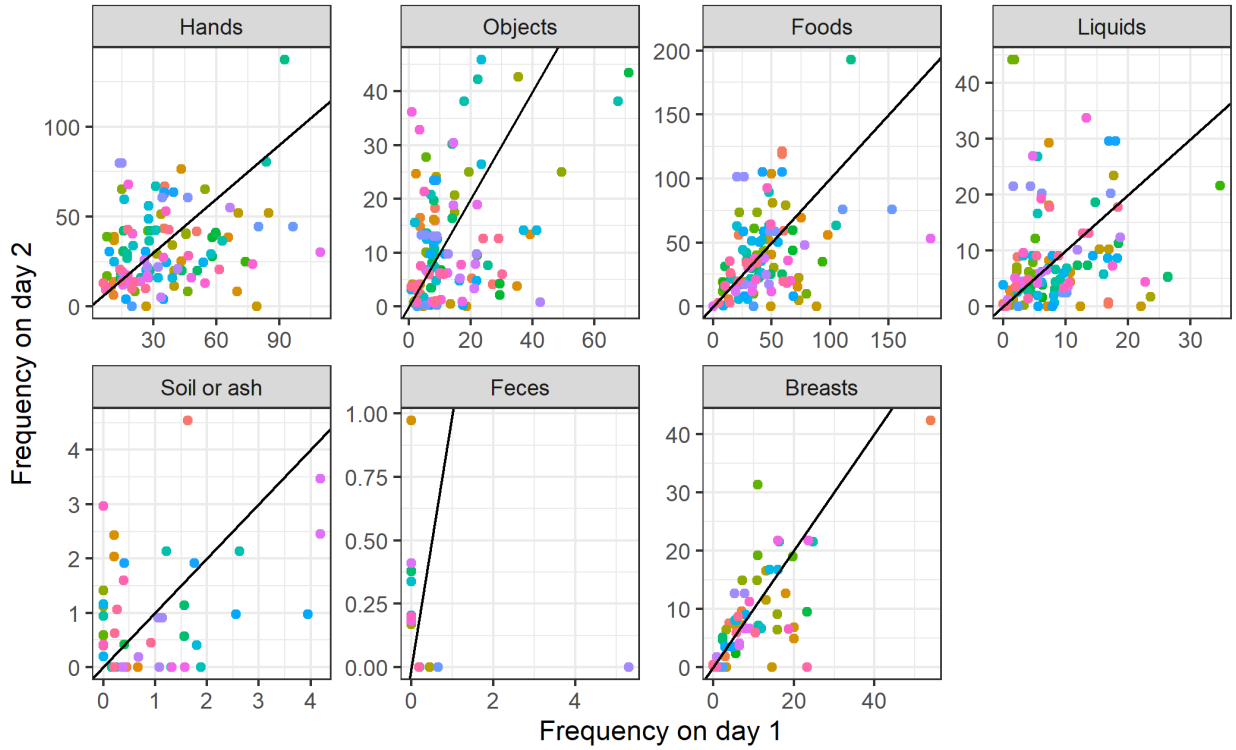
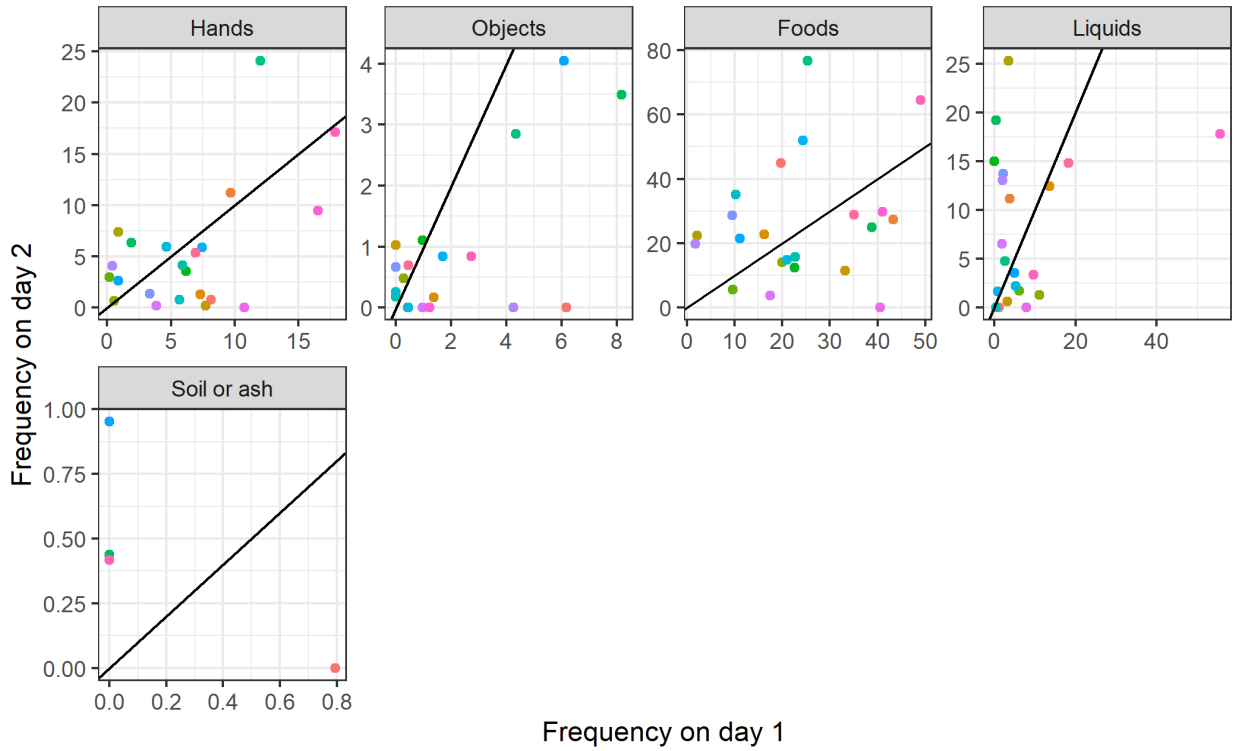


Figure 10. Day-to-day variation in hand- and object-mouthing among young children in rural Uganda. The black line indicates perfect correlation

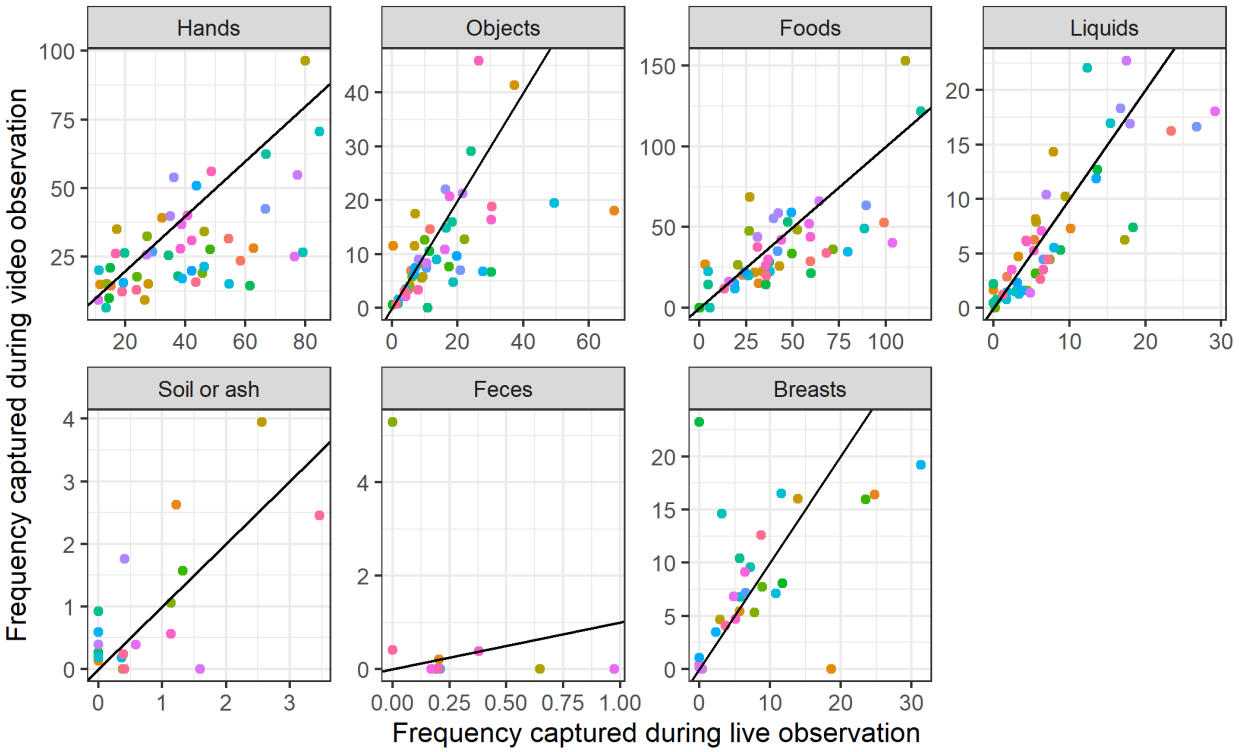
Day-to-day variation among pregnant women

The Pearson correlation coefficient for observations of the same pregnant woman conducted within 10 days was 0.54 for hand mouthing, 0.66 for object mouthing, -0.77 for soil mouthing, 0.22 for putting food in the mouth, and 0.29 for putting liquid in the mouth; no pregnant woman was observed mouthing feces (Figure 11). This degree of correlation is low, though higher than it is for children, indicating that day-to-day variation is high and that mouthing data from a child captured on any given day does not reflect mouthing data on any other day.



3.3.10 Mouthing Frequencies by Video Observation vs. Live Capture

The Pearson correlation coefficient for two observations conducted simultaneously, one with data generated by coding a video recording of the observation and the other through real-time coding of the observation, was 0.60 for hand mouthing, 0.58 for object mouthing, 0.72 for soil mouthing, -0.38 for feces mouthing, 0.72 for putting food in the mouth, and 0.81 for putting liquid in the mouth (Figure 10). The recorded frequency of hand, object, and food mouthing was typically higher during the live observation than the video observation, but lower for soil mouthing (Figure 12). This is a relatively low degree of correlation. By comparison, if every mouthing event recorded during the live observation was also recorded during the video observation, the correlation would be one. These results do not indicate if data from live or video observations more accurately reflects the truth; some evidence may be derived from further review of the video data to assess how well the video data captures what happened in the videos.


Hands
Objects
Foods
Liquids
Soil or ash
Feces
Breasts
Frequency captured during video observation
Frequency captured during live observation

4.0 PART 3. EXPOSURE TO DUST ON IMPROVED AND UNIMPROVED FLOORS

4.1 INTRODUCTION

Unimproved floors may collect and sustain pathogenic organisms as they are moist and difficult to clean. Improved flooring may reduce pathogen sequestration and viability through multiple mechanisms:

1) Improved flooring is drier than unimproved flooring. Natural flooring and drier environments are less supportive of pathogen survival and growth. By example, in Bangladesh, courtyard soil with lower moisture content was associated with lower levels of *E. coli* contamination (Ercumen et al. 2018).
2) Improved flooring is smoother than unimproved flooring and has less surface area for bacterial attachment (Frost and DeJong 2005).
3) Improved flooring is easier to clean because it is smooth and water-resistant and can therefore be easily swept and mopped. Ease of washing likely correlates to more frequent washing and removal of pathogens.

Existing data demonstrates that concrete floors have a lower prevalence and concentration of *E. coli* contamination compared to unimproved floors. A study of 199 households in Dhaka, Bangladesh found 87 percent of households with concrete floors and 13 percent with earthen floors. About a quarter (24%) of concrete floors were positive for *E. coli* (geometric mean 8 MPN/cm^2, arithmetic mean 17 MPN/cm^2) compared to 62 percent of earthen floors (geometric mean 77 MPN/cm^2, arithmetic mean 424 MPN/cm^2) (A. Pickering, personal communication). In addition, in peri-urban homes in the Peruvian Amazon (N = 63), concrete floors were significantly less contaminated with *E. coli* than dirt floors both at the household entrance (0.0 $\log_{10}$ vs. 0.8 $\log_{10}$ *E. coli* CFU/cm^2) and in the kitchen (0.0 $\log_{10}$ vs 1.3 $\log_{10}$ *E. coli* CFU/cm^2) (Exum et al. 2016). In addition, a study in Bangladesh found that nearly all courtyard soil is fecally contaminated and the contamination in soil is associated with increased fecal contamination of hands, water, and food, suggesting that pathogens can be transferred from the floor to the rest of the domestic environment, transmitting disease through multiple pathways (Ercumen et al. 2017).

4.2 METHODS

Field staff collected dust from 92 homes with at least one room that had improved (EarthEnable) flooring that had been installed for at least 6 months. An additional 92 homes with only dirt floors were observed. For the purposes of this study, dust is defined as soil that is indoors (Özkaynak et al. 2011). Field staff first placed a 50 cm x 50 cm ethanol-sterilized, metal wire stencil in the room at a distance of 50 cm from the threshold of the door. Dust was collected by sweeping the floor area inside the stencil by sweeping horizontally and vertically, then again horizontally and vertically with an ethanol-sterilized paintbrush. Field staff swept the collected dust into a 100 mL bag. They swept one to eight adjacent 50 cm x 50 cm areas until they had approximately 50 mL of dust or had swept eight adjacent areas, whichever came first. Dust was never collected from the 50 cm^2 area immediately in front of the door. To calculate the load of dust on the floor, they divided the mass of collected dust by the sampled surface area.

4.3 RESULTS AND DISCUSSION

The median load of dust on dirt floors was 141.1 g/m^2, which is almost nine times higher than the load of dust on EarthEnable floors 16.4 g/m^2 (Figure 13 and Table 10). This finding, along with background evidence that soil on improved floors is less contaminated than soil on unimproved floors (Exum et al. 2016), indicates that children who spend time on improved floors have substantially lower exposure to fecal contamination compared to children who spend the same amount of time on unimproved floors.

Approximately 5 g of dust would be useful for laboratory analysis of *E. coli* and soil moisture content, and an additional 10 g would be useful for polymerase chain reaction analysis of soil-transmitted helminths. Of the samples gathered, 21 percent of EarthEnable floors had less than 5 g of dust and 49 percent had less than 15 g of dust.

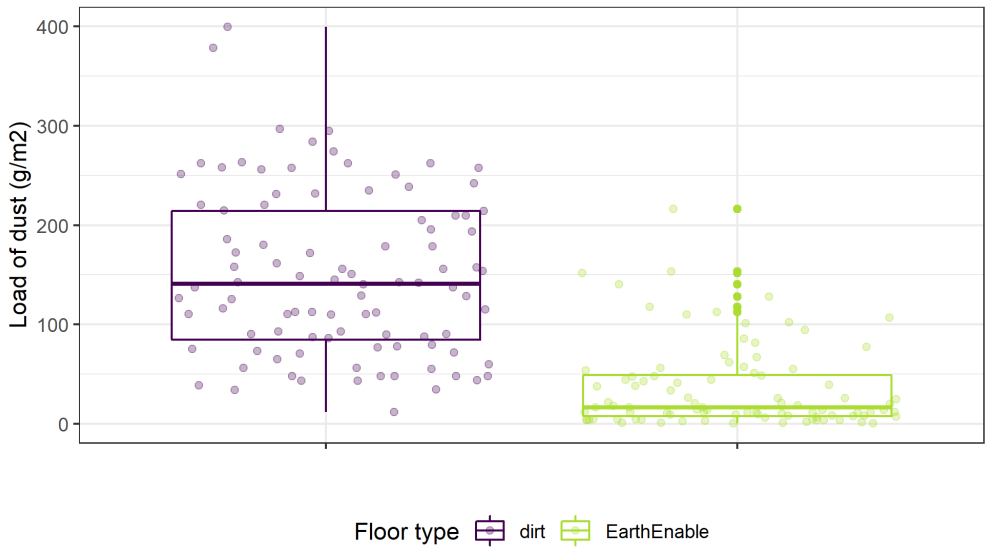


Figure 13. Load of dust on dirt and EarthEnable floors in rural Uganda

Table 10. Load of dust on improved and unimproved floors

		Load of dust (g/m^2)				
Floor type	**N**	**Mean**	**Sd**	**Median**	**Min**	**Max**
Unimproved (dirt)	96	150.1	82.9	141.1	11.7	399.7
Improved (EarthEnable)	92	35.9	42.8	16.4	0.5	216.1

Collected data shows the amount of dust resting on top of household flooring that is potentially contaminated with feces and accessible for the child to mouth. To better understand the amount of fecal contamination that is attached to the floor, the research team plans to sponge floor surfaces and assess the amount of *E. coli* rinsed from the sponge. This work was severely delayed by strict COVID-19 travel restrictions and curfews.

5.0 CONCLUSIONS AND RECOMMENDATIONS

While children spend most of their daylight and evening hours outside the house and have lower mouthing frequencies inside as compared to outside, the feasibility and appeal of improved flooring, changes in hygiene-related behaviors in households with improved floors, and lower loads of dust on improved floors suggest that improved floors are a motivating technology. In contexts where children spend a substantial portion of their time outdoors rather than indoors, improved flooring alone likely offers infants and young children limited protection from environmental pathogens despite increased cleanliness of spaces that have improved flooring. However, if combined with other activities, such as animal feces management, improved flooring may be an important component of creating a hygienic environments for infants and young children. To increase uptake of improved flooring, implementing organizations and market actors should promote affordable, non-concrete improved floors as aspirational endpoints rather than steppingstones. Actors should also discuss with customers and beneficiaries the gender-specific, non-health benefits such as reduced workload and increased status and respect.

Based on study findings, EarthEnable will advocate at the district and national levels in Uganda for government policy, guidance, and/or support to improve housing infrastructure and increase the number of rural households that have improved floors. EarthEnable has already signed a memorandum of understanding with the Rwandan Ministry of Local Government, which enables the Ministry to fund the construction of EarthEnable floors through their human security budget or via partner organizations.

Increasing Sales within EarthEnable

The qualitative findings from this study suggest that improved floors may reduce children's exposure to fecal contamination in the domestic environment through the adoption of behaviors that prevent entry of dirt, feces, and pathogens into the house, and through more frequent and/or thorough cleaning of the household floor. Given that increasing the uptake of improved floors may benefit child health, this report briefly discusses methods that could be used to increase uptake. Several factors influenced households in their choice of housing materials other than factors associated with health and safety. Factors included the likelihood of housing materials to harbor pests, flammability, affordability, availability of natural resources, convenience, durability, cleanability, beauty, comfort, modernity, and respect.

Improved flooring sales agents could target households that are more likely to purchase a floor by noting the house's existing construction materials. All but one of the households we visited had some improved flooring in the house and none had improved flooring in every room of the house, but all had a roof made of corrugated iron and walls made of burnt brick. The qualitative interviews suggest that households prioritized improving their roof first, then walls, then floor. Iron roofs were prioritized first because they were viewed as a prerequisite to protecting the house's walls and floors. Burnt brick walls may have been prioritized over improved flooring because the materials are easier to procure than the materials for improved floors and household members can make burnt bricks themselves. It is unlikely that a household will install improved floors before they have constructed an improved roof and improved walls. Interventions focused on improved flooring will be most successful if they target households that already have an improved roof and improved walls.

Improved flooring companies that do not offer a concrete option could focus on branding their product as a desirable end, rather than as a steppingstone to concrete. The field team observed that many households chose to live with loosely packed dirt floors instead of constructing compacted earthen floors, even though the materials necessary for compacted floors were locally available and the floors could be produced with the household's own labor. During informal discussions with community members, one participant who lived in a home with a dirt floor noted that some homes in the region historically had compacted earthen floors made from laterite (locally called "*marum*"), the same material EarthEnable uses in construction. This indicates that compacted earthen floors were at one point an endpoint in and of themselves, an alternative to concrete floors, rather than on the pathway to concrete floors. However, none of the interviewed households had or mentioned desiring compacted earth floors. While *marum* is locally available, it can only be installed by skilled laborers. It also degrades over a few months to resemble and feel like a regular, non-compacted dirt floor.

Some respondents said they preferred not to invest in an EarthEnable floor, a relatively unknown technology of unknown quality, because they would rather save their money for a concrete floor, a known technology with a known quality. With an eye on the future, some said they might choose to construct dirt floors while planning to eventually construct concrete floors. Investing in compacted floors in the meantime was considered a useless investment of time, energy, and money.

Households will be more likely to install improved floors that are low-cost and do not require special skills to install or maintain. Households also want to be confident of the quality of the material before using it, so demonstration houses made of the material could be useful. Materials should be locally available. Even if materials are free, if they are not conveniently available in sufficient quantities, then households will not want to build with them. Materials should result in surfaces that are easy to clean, reflect that they are clean, and are beautiful when they are clean.

Several sales and marketing strategies could increase uptake of improved flooring by effectively addressing misconceptions, gender roles, and power dynamics related to the installation of improved flooring. To address the misconception that innovative, low-cost improved floors such as EarthEnable floors are only an incremental step toward better-quality concrete floors, producers should showcase a demonstration house in each location where improved flooring is being promoted. EarthEnable has recently focused on improving the quality of its product and has integrated new measures to manage moisture-related issues in Uganda. Staff could use demonstration homes to explain these improvements and demonstrate how the new EarthEnable floors are of much higher quality than the EarthEnable floors installed previously. To address the fact that women who are not the heads of their households may need to make decisions jointly with adult males in their household or convince an adult male who makes the final decision, sales representatives can emphasize the gender-specific attributes valued by men and women. For example, sales representatives could remind men that people with improved floors feel more comfortable hosting guests and are often perceived to have a higher status than those with dirt floors. Sales representatives could also emphasize the cost savings on soap related to reduced laundering. To women, they might pitch that improved floors foster personal dignity and confidence. They might emphasize that personal actions facilitate improved health outcomes for children. And they might highlight the time and energy saved on less frequent laundering and general cleaning. Sales representatives could also encourage women to talk to men about these benefits. If a woman feels that she reaps a sufficient degree of benefit from the improved floor, she may commit her own labor to constructing a do-it-yourself EarthEnable floor. Finally, sales agents that are of the same gender as the

potential customer may be more effective than sales agents of opposite genders (International Development Enterprises (iDE) 2019).

Increasing Uptake of Improved Floors through Partnerships

EarthEnable has been in conversation with implementers such as the Water Trust and PSI to become master franchisees of EarthEnable. EarthEnable has talked to these partners and others about potential synergies between other water, sanitation, and hygiene activities and EarthEnable floor installation. For example, some joint installations of EarthEnable floors and WASH infrastructure have already begun with WASH projects in Rwanda, conducted jointly by Catholic Relief Services and USAID. Within EarthEnable, EarthEnable sales and other staff will discuss the findings from Part 1 to promote improved flooring more effectively.

REFERENCES

Aderoba, Adeniyi K., Oseihie I. Iribhogbe, Biodun N. Olagbuji, Oghenefegor E. Olokor, Chiedozie K. Ojide, and Adedapo B. Ande. 2015. "Prevalence of Helminth Infestation during Pregnancy and Its Association with Maternal Anemia and Low Birth Weight." *International Journal of Gynecology & Obstetrics* 129 (3): 199–202. https://doi.org/10.1016/j.ijgo.2014.12.002.

Adriko, Moses, Benjamin Tinkitina, Moses Arinaitwe, Narcis B. Kabatereine, Mariam Nanyunja, and Edridah M. Tukahebwa. 2018. "Impact of a National Deworming Campaign on the Prevalence of Soil-Transmitted Helminthiasis in Uganda (2004-2016): Implications for National Control Programs." Edited by Amadou Garba. *PLOS Neglected Tropical Diseases* 12 (7): e0006520. https://doi.org/10.1371/journal.pntd.0006520.

Agency for Toxic Substance and Disease Registry. 2002. "Toxicological Profile for DDT, DDE, and DDD." Atlanta, Georgia: Agency for Toxic Substances and Disease Registry.

Bankole, S., M. Schollenberger, and W. Drochner. 2006. "Mycotoxins in Food Systems in Sub Saharan Africa: A Review." *Mycotoxin Research* 22 (3): 163–69. https://doi.org/10.1007/BF02959270.

Benjamin-Chung, Jade, Yoshika S Crider, Andrew Mertens, Ayse Ercumen, Amy J Pickering, Audrie Lin, Lauren Steinbaum, et al. 2021. "Household Finished Flooring and Soil-Transmitted Helminth and Giardia Infections among Children in Rural Bangladesh and Kenya: A Prospective Cohort Study." *The Lancet Global Health* 9 (3): e301–8. https://doi.org/10.1016/S2214-109X(20)30523-4.

Cantu-Soto, E. U., Maria Mercedes Meza-Montenegro, A. I. Valenzuela-Quintanar, A. Félix-Fuentes, P. Grajeda-Cota, J. J. Balderas-Cortes, C. L. Osorio-Rosas, G. Acuña-García, and M. G. Aguilar-Apodaca. 2011. "Residues of Organochlorine Pesticides in Soils from the Southern Sonora, Mexico." *Bulletin of Environmental Contamination and Toxicology* 87 (5): 556–60. https://doi.org/10.1007/s00128-011-0353-5.

Cattaneo, Matias D, Sebastian Galiani, Paul J Gertler, Sebastian Martinez, and Rocio Titiunik. 2009. "Housing, Health, and Happiness." *American Economic Journal: Economic Policy* 1 (1): 75–105. https://doi.org/10.1257/pol.1.1.75.

Cicchetti, Domenic V. 1994. "Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instruments in Psychology" 6 (4): 7.

Douglas, Mary, and Baron Isherwood. 1966. *The World of Goods*. Routledge.

Ercumen, Ayse, Andrew Mertens, Benjamin F. Arnold, Jade Benjamin-Chung, Alan E. Hubbard, Mir Alvee Ahmed, Mir Himayet Kabir, et al. 2018. "Effects of Single and Combined Water, Sanitation and Handwashing Interventions on Fecal Contamination in the Domestic Environment: A Cluster-Randomized Controlled Trial in Rural Bangladesh." *Environmental Science & Technology* 52 (21): 12078–88. https://doi.org/10.1021/acs.est.8b05153.

Ercumen, Ayse, Amy J. Pickering, Laura H. Kwong, Benjamin F. Arnold, Sarker Masud Parvez, Mahfuja Alam, Debashis Sen, et al. 2017. "Animal Feces Contribute to Domestic Fecal Contamination: Evidence from *E. Coli* Measured in Water, Hands, Food, Flies, and Soil in Bangladesh." *Environmental Science & Technology* 51 (15): 8725–34. https://doi.org/10.1021/acs.est.7b01710.

Exum, Natalie G., Maribel Paredes Olórtegui, Pablo Peñataro Yori, Meghan F. Davis, Christopher D. Heaney, Margaret Kosek, and Kellogg J. Schwab. 2016. "Floors and Toilets: Association of Floors and Sanitation Practices with Fecal Contamination in Peruvian Amazon Peri-Urban Households." *Environmental Science & Technology* 50 (14): 7373–81. https://doi.org/10.1021/acs.est.6b01283.

Ezeamama, Amara E., Jennifer F. Friedman, Luz P. Acosta, David C. Bellinger, Gretchen C. Langdon, Daria L. Manalo, Remigio M. Olveda, Jonathan D. Kurtis, and Stephen T. Mcgarvey. 2005. "Helminth Infection and Cognitive Impairment among Filipino Children." *The American Journal of Tropical Medicine and Hygiene* 72 (5): 540–48. https://doi.org/10.4269/ajtmh.2005.72.540.

Florey, Liz, and Cameron Taylor. 2016. "Using Household Survey Data to Explore the Effects of Improved Housing Conditions on Malaria Infection in Children in Sub-Saharan Africa (DHS Analytical Studies 61)." Rockville, Maryland, USA: ICF International.

Frost, J. David, and Jason T. DeJong. 2005. "In Situ Assessment of Role of Surface Roughness on Interface Response." *Journal of Geotechnical and Geoenvironmental Engineering* 131 (4): 498–511. https://doi.org/10.1061/(ASCE)1090-0241(2005)131:4(498).

George, Christine Marie, Lauren Oldja, Gwenyth O. Lee, Shwapon Biswas, Jamie Perin, Gwenyth O. Lee, Margaret Kosek, et al. 2015. "Geophagy Is Associated with Environmental Enteropathy and Stunting in Children in Rural Bangladesh." *The American Journal of Tropical Medicine and Hygiene* 92 (6): 1117–24. https://doi.org/10.4269/ajtmh.14-0672.

Gorman Ng, Melanie, Alice Davis, Martie van Tongeren, Hilary Cowie, and Sean Semple. 2016. "Inadvertent Ingestion Exposure: Hand- and Object-to-Mouth Behavior among Workers." *Journal of Exposure Science & Environmental Epidemiology* 26 (1): 9–16. https://doi.org/10.1038/jes.2014.71.

Guyatt, H. 2000. "Do Intestinal Nematodes Affect Productivity in Adulthood?" *Parasitology Today* 16 (4): 153–58. https://doi.org/10.1016/S0169-4758(99)01634-8.

Haefliger, Pascal, Monique Mathieu-Nolf, Stephanie Lociciro, Cheikh Ndiaye, Malang Coly, Amadou Diouf, Absa Lam Faye, et al. 2009. "Mass Lead Intoxication from Informal Used Lead-Acid Battery Recycling in Dakar, Senegal." *Environmental Health Perspectives* 117 (10): 1535–40. https://doi.org/10.1289/ehp.0900696.

International Development Enterprises (iDE). 2019. "Understanding How Sanitation Sales Agent Gender Affects Key Sanitation Behaviors in Nepal."

Isiko, Alexander Paul. 2019. "The Nexus between Traditional Healing and Societal Organisation: Reflections on Busoga Society Socio–Cultural, Economic and Political Organisation." *Journal of Arts and Humanities* 08 (08): 18.

Jenkins, Marion. 1999. "Sanitaiton Promotion in Developing Countries: Why the Latrines of Benin Are Few and Far Between." Davis, California: University of California, Davis.

Kwong, Laura H., Ayse Ercumen, Amy J. Pickering, Joanne E. Arsenault, Mahfuza Islam, Sarker M Parvez, Leanne Unicomb, Mahbubur Rahman, Jennifer Davis, and Stephen P. Luby. 2020. "Ingestion of Fecal Bacteria along Multiple Pathways by Young Children in Rural Bangladesh Participating in a Cluster-Randomized Trial of Water, Sanitation, and Hygiene Interventions (WASH Benefits)." *Environmental Science & Technology* 54 (21): 13828–38. https://doi.org/10.1021/acs.est.0c02606.

Kwong, Laura H., Ayse Ercumen, Amy J. Pickering, Leanne Unicomb, Jennifer Davis, James O. Leckie, and Stephen P. Luby. 2019. "Soil Ingestion among Young Children in Rural Bangladesh." *Journal of Exposure Science & Environmental Epidemiology* xx (xx): xx. https://doi.org/10.1038/s41370-019-0177-7.

Kwong, Laura H., Ayse Ercumen, Amy J. Pickering, Leanne Unicomb, Jennifer Davis, and Stephen P. Luby. 2020. "Age-Related Changes to Environmental Exposure: Variation in the Frequency That Young Children Place Hands and Objects in Their Mouths." *Journal of Exposure Science & Environmental Epidemiology* 30: 205–16. https://doi.org/10.1038/s41370-019-0115-8.

Luoba, Alfred I., P. Wenzel Geissler, Benson Estambale, John H. Ouma, Dorcas Alusala, Rosemary Ayah, David Mwaniki, Pascal Magnussen, and Henrik Friis. 2005. "Earth-Eating and Reinfection with Intestinal Helminths among Pregnant and Lactating Women in Western Kenya." *Tropical Medicine and International Health* 10 (3): 220–27. https://doi.org/10.1111/j.1365-3156.2004.01380.x.

Mattioli, Mia Catharine M., Jennifer Davis, and Alexandria B. Boehm. 2015. "Hand-to-Mouth Contacts Result in Greater Ingestion of Feces than Dietary Water Consumption in Tanzania: A Quantitative Fecal Exposure Assessment Model." *Environmental Science & Technology* 49 (3): 1912–20. https://doi.org/10.1021/es505555f.

McGraw, Kenneth O. 1996. "Forming Inferences about Some Intraclass Correlatin Coefficients_correction.Pdf." *Psychological Methods* 1 (1): 30–46.

Medgyesi, Danielle, John Brogan, Daniel Sewell, Jean Creve-Coeur, Laura Kwong, and Kelly Baker. 2018. "Where Children Play: Young Child Exposure to Environmental Hazards during Play in Public Areas in a Transitioning Internally Displaced Persons Community in Haiti." *International Journal of Environmental Research and Public Health* 15 (8): 1646. https://doi.org/10.3390/ijerph15081646.

Mpairwe, H., R. Tweyongyere, and A. Elliott. 2014. "Pregnancy and Helminth Infections." *Parasite Immunology* 36 (8): 328–37. https://doi.org/10.1111/pim.12101.

Mukherjee, Amitava, Mrinal Kumar Sengupta, M. Amir Hossain, Sad Ahamed, Bhaskar Das, Bishwajit Nayak, Dilip Lodh, Mohammad Mahmudur Rahman, and Dipankar Chakraborti. 2006. "Arsenic Contamination in Groundwater: A Global Perspective with Emphasis on the Asian Scenario." *Journal of Health, Population and Nutrition* 24 (2,): 142–63. http://www.jstor.org/stable/23499353.

Ngure, F. M., J. H. Humphrey, M. N. N. Mbuya, F. Majo, K. Mutasa, M. Govha, E. Mazarura, et al. 2013. "Formative Research on Hygiene Behaviors and Geophagy among Infants and Young Children and Implications of Exposure to Fecal Bacteria." *American Journal of Tropical Medicine and Hygiene* 89 (4): 709–16. https://doi.org/10.4269/ajtmh.12-0568.

Owada, K, M Nielsen, CL Lau, ACA Clements, L Yakob, and RJ Soares Magalhaes. 2017. "Measuring the Effect of Soil-Transmitted Helminth Infections on Cognitive Function in Children: Systematic Review and Critical Appraisal of Evidence." *Adv Parasitol*. https://doi.org/10.1016/bs.apar.2017.05.002.

Özkaynak, Halûk, Jianping Xue, Valerie G. Zartarian, Graham Glen, and Luther Smith. 2011. "Modeled Estimates of Soil and Dust Ingestion Rates for Children: Soil and Dust Ingestion." *Risk Analysis* 31 (4): 592–608. https://doi.org/10.1111/j.1539-6924.2010.01524.x.

Schnall, Simone, Jennifer Benton, and Sophie Harvey. 2008. "With a Clean Conscience: Cleanliness Reduces the Severity of Moral Judgments." *Psychological Science* 19 (12): 1219–22. https://doi.org/10.1111/j.1467-9280.2008.02227.x.

Shivoga, William A., and Wilkister N. Moturi. 2009. "Geophagia as a Risk Factor for Diarrhoea." *The Journal of Infection in Developing Countries* 3 (02). https://doi.org/10.3855/jidc.55.

Sklar, Rachel, Zeyi Zhou, Marley Zalay, Ashley Muspratt, and S. Katharine Hammond. 2019. "Occupational Exposure to Endotoxin along a Municipal Scale Fecal Sludge Collection and Resource Recovery Process in Kigali, Rwanda." *International Journal of Environmental Research and Public Health* 16 (23): 4740. https://doi.org/10.3390/ijerph16234740.

Smith, K. R. 2000. "National Burden of Disease in India from Indoor Air Pollution." *Proceedings of the National Academy of Sciences* 97 (24): 13286–93. https://doi.org/10.1073/pnas.97.24.13286.

Teunis, Peter F. M., Heather E. Reese, Clair Null, Habib Yakubu, and Christine L. Moe. 2016. "Quantifying Contact with the Environment: Behaviors of Young Children in Accra, Ghana." *The American Journal of Tropical Medicine and Hygiene* 94 (4): 920–31. https://doi.org/10.4269/ajtmh.15-0417.

Uganda Bureau of Statistics (UBOS) and ICF. 2018. "Uganda Demographic and Health Survey 2016." Kampala, Uganda and Rockville, Maryland, USA.

U.S. Environmental Protection Agency. 2005. "Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants." EPA/630/P-03/003F. Washington D.C.: U.S. Environmental Protection Agency.

———. 2011. "Exposure Factors Handbook." EPA/600/R-090/052F. Washington D.C.: U.S. Environmental Protection Agency.

Wang, Yuke, Christine L. Moe, Clair Null, Suraja J. Raj, Kelly K. Baker, Katharine A. Robb, Habib Yakubu, et al. 2017. "Multipathway Quantitative Assessment of Exposure to Fecal Contamination for Young Children in Low-Income Urban Environments in Accra, Ghana: The Sanipath Analytical Approach." *The American Journal of Tropical Medicine and Hygiene* 97 (4): 1009–19. https://doi.org/10.4269/ajtmh.16-0408.

Xue, Jianping, Valerie Zartarian, Jacqueline Moya, Natalie Freeman, Paloma Beamer, Kathy Black, Nicolle Tulve, and Stuart Shalat. 2007. "A Meta-Analysis of Children's Hand-to-Mouth Frequency Data for Estimating Nondietary Ingestion Exposure." *Risk Analysis* 27 (2): 411–20. https://doi.org/10.1111/j.1539-6924.2007.00893.x.

Xue, Jianping, Valerie Zartarian, Nicolle Tulve, Jacqueline Moya, Natalie Freeman, Willa AuYeung, and Paloma Beamer. 2010. "A Meta-Analysis of Children's Object-to-Mouth Frequency Data for Estimating Non-Dietary Ingestion Exposure." *Journal of Exposure Science & Environmental Epidemiology* 20: 536–45.

Ziegelbauer, Kathrin, Benjamin Speich, Daniel Mäusezahl, Robert Bos, Jennifer Keiser, and Jürg Utzinger. 2012. "Effect of Sanitation on Soil-Transmitted Helminth Infection: Systematic Review and Meta-Analysis." Edited by Simon Hales. *PLoS Medicine* 9 (1): e1001162. https://doi.org/10.1371/journal.pmed.1001162.

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov