TOWARD A HYGIENIC ENVIRONMENT FOR INFANTS AND YOUNG CHILDREN

LIMITING EARLY EXPOSURES TO SUPPORT LONG-TERM HEALTH AND WELL-BEING

JANUARY 2022

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Dr. Laura (Layla) Kwong (University of California Berkeley School of Public Health) and Julia Rosenbaum (FHI360) developed this report, drawing on a number of WASHPaLS reports and publications produced over the life of the project. This document summarizes and updates the 2018 *Desk Review: Toward a Hygienic Environment for Infants and Young Children: A Review of the Literature* and presents WASHPaLS and other new research through the hygienic environments lens.

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ACRONYMS AND ABBREVIATIONS

BCC	Behavior Change Communications
CFM	Child Feces Management
CFU	Colony Forming Unit
CLTS	Community-Led Total Sanitation
EED	Environmental Enteric Dysfunction
FIB	Fecal Indicator Bacteria
HAZ	Height-for-Age Z Score
HHV	Household Visit
icddr,b	International Centre for Diarrheal Disease Research, Bangladesh
IYC	Infants and Young Children
LMICs	Lower- and Middle-Income Countries
MAL-ED	Malnutrition and the Consequences for Child Health and Development
MST	Microbial Source Tracking
NEAP	Neighborhood-based Environmental Assessment and Planning
NGO	Nongovernmental Organization
NOURISH	USAID Integrated Nutrition, Hygiene, and Sanitation Project
OD	Open Defecation
ODF	Open Defecation Free
PRO-WASH	Practices, Research, and Operations in Water, Sanitation, and Hygiene
RCT	Randomized Control Trial
SDW	Stored Drinking Water
SHINE	Sanitation Hygiene Infant Nutrition Efficacy Trial
TIPS	Trials of Improved Practices
UCD	User-Centered Design
USAID	United States Agency for International Development
WASH	Water, Sanitation, and Hygiene
WASHPaLS	Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability project
WAZ	Weight-for-Age Z-Score
WHZ	Weight-for-Height Z-Score

1.0 INTRODUCTION AND PURPOSE

Direct ingestion of animal and human feces in soil as well as exploratory mouthing by infants and young children remain underemphasized pathways of fecal pathogen exposure impacting child health and growth, as highlighted in the 2018 Water, Sanitation, and Hygiene Partnerships and Learning for Sustainability Program (WASHPaLS) desk review, "Toward a Hygienic Environment for Infants and Young Children" (USAID, 2018).

For decades the seminal "F-diagram" has been used to depict routes of pathogen transmission from human feces to a new host via fluids, fields (floors, earth, dirt), flies, fingers, fomites (surfaces), and food. The classical F-diagram focuses exclusively on human excreta, tracing transmission of pathogens through different exposure routes; culminating in diarrheal morbidity and mortality. Traditional water, sanitation, and hygiene (WASH) interventions to disrupt transmission via these pathways have conventionally focused on increasing access to improved water, hand hygiene and sanitation measures. When focusing specifically on infants and young children (IYC), it is increasingly clear this framework inadequately presents the comprehensive set of causal pathways and interventions to disrupt them. This may partially explain why achieving widespread reductions in childhood infections remains elusive, despite decades of nutrition and WASH interventions.

The following review updates the 2018 desk review cited above, focusing on recent peer-reviewed and gray literature on behavior change innovations that address domestic animal excreta in home environments (infant playpens, poultry cooping and feces management), safe disposal of infant feces, food hygiene, and improved flooring—all behavior-product combinations with the potential to protect IYC. The evidence does not yet point clearly to best practice, but implications for implementation programming are discussed, including alignment with USAID WASH and development technical briefs on Social and Behavior Change for WASH and WASH and its Links to Nutrition.

For readers with a comprehensive grasp of the sources of fecal contamination, as well as current documentation of the varied infant-specific pathways affecting IYC health and growth, the team invites the reader to go directly to Section 3 of this document, which details and discusses recent studies on interventions to interrupt contamination pathways, as well as the discussion and recommendations outlined in Section 4.

2.0 FECAL CONTAMINATION AND PATHOGEN TRANSMISSION PATHWAYS

Human and animal fecal contamination of household environments is pervasive in lower- and middle-income countries (LMICs), where unhygienic management of child, adult, and animal feces is common. Even when children or adults defecate in a latrine, fecal sludge may not be disposed of properly. Fecal contamination can also enter the environment through inappropriate wastewater conveyance and use of animal feces for fuel and housing material.

Environmental contamination by human feces due to open defecation (OD) and unhygienic fecal sludge management represents a key risk factor for diarrhea. Fecal matter may contain enteric pathogens, including bacteria (*Campylobacter jejuni*, enteropathogenic strains of *Escherichia coli*, and *Salmonella* species), viruses (norovirus, rotavirus, astrovirus), and protozoa (*Giardia,* Cryptosporidium), as well as other infectious disease agents (Nasrin et al., 2021). Historically studies have focused on adults, so in this review the team focuses on the understudied sources of child and animal feces, as well as on the pathogen transmission pathways that most impact infants and young children.

2.1 SOURCES OF FECAL CONTAMINATION

Child Feces. Unsafe management of child excreta is common in many countries (Rand et al., 2015; Freeman et al., 2016; Majorin et al., 2014; Miller-Petrie et al., 2016; Mara et al., 2010; George et al., 2016; Gil et al., 2004; Seidu, 2021). Unsafe disposal is defined as feces that are not deposited into any kind of improved or unimproved toilet or latrine. For children that do not defecate in a latrine by themselves, safe disposal of child feces requires caregivers to help the child use the latrine or for caregivers to safely collect the child feces and then dispose of them in a latrine (Rand et al., 2015).

Safe child feces disposal is more likely among households that did not have any household members practicing open defecation and wealthier households (Rand et al., 2015; Sahiledengle, 2019; Islam et al., 2018; Beardsley et al., 2021), but even in households with improved sanitation, safe child feces disposal may be uncommon (Rand et al., 2015). In Bangladesh, safe child feces disposal was more likely among households that reported child potty use or that adults always defecated in a latrine. Reported disposal practices had high sensitivity but low positive predictive value of observed practices (Islam et al., 2018). In analyses of demographic and health surveillance data, safe disposal was independently associated with a number of factors, including child age, household wealth, no adult household members practicing OD, not being married, the female household head having attended primary school, fewer than five children in the household, and improved water or sanitation (Seidu, 2021; Beardsley et al., 2021; Rand et al., 2015; Sahiledengle, 2019).

One reason safe child feces disposal is more likely for older children is because older children are more likely to use a latrine (Huda et al., 2019; Rand et al., 2015; Sahiledengle, 2019). Another is because the feces of young children may be perceived as pure (Chebet et al., 2020; Ellis et al., 2020). Lack of time to locate children's defecation sites and the lack of time and materials to safely collect and dispose of child feces are two additional constraints to safe child feces management (CFM) (Ellis et al., 2020; Huda et al., 2021). Beliefs about how feces collection and disposal practices may influence children also shape practices. For example, in a small qualitative study in rural Tanzania (n = 7 focus group discussions), community members believed that picking up child feces with a hard tool would physically harm the child and that disposal of child feces in a latrine would prevent developmental milestones or otherwise hurt the child (Chebet et al., 2020).

Unsafe child feces disposal contaminates the household environment. Young children often defecate in locations other than the latrine, and their feces are commonly disposed of unhygienically. In rural India, 64 percent of children <6 years old (n = 188) defecated on the ground or on the floor (Bauza et al., 2020). Even when a paper was laid on the floor prior to defecation, defecating on the ground or on the floor increased *E. coli* contamination of both finished and earthen floors (Bauza et al., 2020). Caregiver hand contamination increased when unsafe feces collection tools (e.g., paper, plastic bag, straw/hay) were used to pick up child feces, but not when safe collection tools (e.g., potty, hoe, scoop) were used (Bauza et al., 2020).

Even the feces of children without diarrhea may be risky. Several multi-countries studies, including the Global Enteric Multicenter Study (GEMS) and the Etiology, Risk Factors, and Interactions of Enteric Infections and Malnutrition and the Consequences for Child Health and Development Study, have found that two-thirds of non-diarrheal stools carry pathogens (Kotloff et al., 2013; Platts-Mills et al., 2015). Inadequate infant feces disposal was associated with a 23 percent increase in the risk of diarrhea among children in Peru (Lanata et al., 1998) and an 11 percent increase among children in India (Bawankule et al., 2017). In a prospective cohort study of children less than 30 months old in rural Bangladesh (George et al., 2016), unsafe disposal of infant feces was associated with elevated levels of some (but not other) markers of environmental enteric dysfunction (EED; a subclinical condition characterized by blunted intestinal villi and an inflamed intestine that has impaired absorption), lower weight-for-height z-scores (WHZ), and lower weight-for-age z-scores (WAZ).

Animal Feces. Households may keep poultry, ruminants and other animals as a form of nutrition, food security, or savings; however, domestic animals generate fecal matter that can contaminate the environment and pose a risk to child health (Mosites et al., 2015; Headey & Hirvonen, 2016; Kaur et al., 2017; Ercumen et al., 2017; Zambrano et al., 2014; Bauza et al., 2018). Animal feces cause widespread contamination of the environment (Penakalapati et al., 2017; Ercumen et al., 2017; Schriewer et al., 2015; Harris et al., 2016; Boehm et al., 2016). In rural Bangladesh, where 85 percent of households have chickens, *E. coli* was detected in 77 percent of stored water, 25 percent of samples of source water, 43 percent of child hand rinses, 58 percent of food, 50 percent of flies, 97 percent of ponds, and 95 percent of soil (Ercumen et al., 2017). In rural India, microbial source tracking (MST) markers of animal fecal contamination were found in 50 percent of stored water, 15 percent of tubewells, 90 percent of hand rinse samples, and 75 percent of ponds, indicating widespread risks of exposure to animal feces and zoonotic pathogens (Schriewer et al., 2015). In a multi-country study, presence of animal feces in the domestic environment was negatively associated with hand cleanliness in mothers and children (Headey & Hirvonen, 2016). These studies document that while sanitation interventions that limit human feces from the environment may reduce transmission, they have shown limited impact on overall environmental contamination (Ercumen et al., 2017).

Animal feces carry a range of pathogens that can infect humans. Several studies have isolated pathogenic bacteria (Simango, 2006; Marquis et al., 1990) and other fecal bacteria from soil and chicken feces sampled from the domestic environment (Pickering & Davis, 2012; Ngure et al., 2013). *Cryptosporidium* and *Giardia* were detected in 12 percent of clinic-admitted diarrhea patients in areas where animal loading estimates suggested cattle were the greatest contributor of *Cryptosporidium* oocysts and *Giardia* cysts to the environment in the region (Daniels et al., 2015). In rural Ethiopia, a small study (n = 35) found 49 percent of children and 69 percent of poultry were infected with *Campylobacter*, which was also found on 66 percent of floors; children who were wasted (low weight for height) had 1.41 increase in odds of carrying *Campylobacter* compared to non-wasted children (Budge et al., 2020). Risk factors for *Campylobacter* infection included owning poultry infected with *Campylobacter;* owning cattle, independent of their infection status; and keeping animals inside (Budge et al., 2020).

Pathogens found in animals cause illness in children. In a recent systematic review, 69 percent of the studies reported an association between exposure to domestic food-producing animals (such as poultry and livestock) and diarrheal illness (Zambrano et al., 2014). Exposure to domestic poultry more than doubled the risk of human *campylobacteriosis*, and failure to identify the microbial cause of disease might have actually underestimated the effect (Zambrano et al., 2014). Elevated prevalence of *Giardia duodenalis* among Ethiopian children was associated with cattle and manure contact (Wegayehu et al., 2013).

Children can be exposed to pathogens in animal feces both directly (by putting animal feces in their mouths) and indirectly (through mouthing objects that have been contaminated with animal feces) (Kwong et al., 2021; Reid et al., 2018; Kwong et al., 2016; George et al., 2015; Ngure et al., 2013; Marquis et al., 1990). Several studies suggest how animal husbandry and animal feces management can influence child health. Formative research among 20 households in Burkina Faso indicates that exposure to the feces of poultry and livestock and unhygienic disposal of CFM were common (Ngure et al., 2019). In rural India, levels of both human and animal (mainly ruminant) fecal contamination in households showed significant associations with subsequent child diarrhea, suggesting that exposure to animal (in addition to human) fecal contamination may increase the risk of child diarrhea in this setting (Odagiri et al., 2016). In a prospective cohort study in Western Kenya, children from households with animals suffering from digestive disorders experienced slower growth than children in households with healthy animals (Mosites et al., 2015).

Explanations offered for this association include the possibility that sick animals were an indicator of household poverty, food shortage, or overall poor household health (Thumbi et al., 2015; Zambrano et al., 2014). Another hypothesis is that sick animals are a source of zoonotic pathogens leading to infectious diarrhea and subsequent growth failure (Checkley et al., 2008; Schlaudecker et al., 2011). Within the same cohort, livestock disease reports were associated with simultaneous human disease reports (Thumbi et al., 2015). While controlling for household size, the odds of human gastrointestinal, febrile, and respiratory illness increased by 31 percent for every 10 cases of animal illness or death observed within the household. Similarly, a 6 and 10 percent increase in the probability of human gastrointestinal and respiratory illness, respectively, was associated with each additional case of the respective illness observed in animals in the same household during the same visit.

A cross-sectional analysis of a large agricultural survey in rural Ethiopia suggests that while poultry ownership may be beneficial to child growth, overnight corralling of poultry within the household dwelling may present a concurrent risk for undernutrition via increased risk of infectious diseases (Headey & Hirvonen 2016). Children in households that allow domestic animals to sleep in the house have a higher risk of adverse health outcomes, such as stunting and EED, compared to children in households where animals do not sleep inside (George et al., 2015; Bender et al., 2004; Headey & Hirvonen, 2016). Poultry, which often carry *Campylobacter,* are particularly risky (Bender et al., 2004). However, a study in Ethiopia found that households with more chickens had *lower* exposure to animal feces and that having a chicken coop was associated with a *higher* likelihood of observing feces in the yard; but among those with a coop, having a coop surrounded by a fence reduced that risk by 83%. Coops that were enclosed, had fencing, and were located further from homes were associated with a reduced risk of observing animal feces and an increased likelihood of children having clean hands. Direct observations showed that chicken coops were often poorly designed or not used (Passarelli et al., 2021).

It is important to note, however, that these costs may co-occur with potential nutritional benefits offered by increased food access from domestic animal husbandry (Kaur et al., 2017). Mosites et al. (2015) report a modest child growth benefit of owning household livestock, with a ten-fold increase of livestock ownership associated with lower stunting prevalence in Ethiopia and Uganda (though not in Kenya). The authors adjusted their analysis for such confounding factors as child age at baseline, child sex, number of household members, household baseline wealth, and baseline household livestock ownership count, concluding that "ownership of healthy livestock may improve child baseline health and decrease the impact of infectious diseases that would otherwise lead to stunting" but that the "pathway has not been well evaluated and further research is needed."

Within a cross-sectional meta- analysis of Demographic and Health Survey data from 30 sub-Saharan African countries, Kaur et al. (2017) reinforces the hypothesis that domestic animal husbandry is, at the same time, "protective against stunting, an indicator of chronic malnutrition, and a risk factor for all-cause mortality in children."[1] They identify 13 countries for which domestic livestock ownership is a risk factor for elevated child diarrhea, but in another 10 found a protective association (Kaur et al., 2017). The authors acknowledge that their results reveal considerable heterogeneity among countries for which further data would be needed to infer the relative costs and benefits of the practices within a particular geography.

2.2 PATHOGEN TRANSMISSION PATHWAYS

In low-resource settings, the domestic environment is often contaminated with child, adult, and animal feces, exposing children to feces when they crawl, eat, and play. Maintenance of personal and household hygiene, as well as inculcating healthy hygiene habits in young children, falls primarily to women who are already constrained by many other demands on their time. The same social and cultural norms that hold women responsible for household hygiene stigmatize caregivers for household contamination and sick children.

The transmission pathways for human- and animal-sourced zoonotic pathogens are multiple and result from normal child behavior, such as eating and exploratory mouthing. IYC may incidentally ingest feces through mouthing soiled fingers, play objects, and household items, as well as direct ingestion of contaminated soil and/or poultry feces, common in both domestic and public spaces in low-income environments (Marquis et al., 1990; Ngure et al., 2013; Reid et al., 2018, Kwong, 2016 George et al., 2015; Medgyesi et al., 2018; Kwong et al., 2020b; Kwong et al., 2021). Indeed, poor hygiene of the domestic environment has been linked to EED and growth faltering (Lin et al., 2013; Ngure, 2012).

Few studies have examined the relative magnitude of importance of various pathways. A study in Tanzania that examined only the hands and water pathway found the majority of contamination to be transferred by the hands (Mattioli et al., 2015). Another study examined children's exposure through contact with hands, water in drains, soil, drinking water, food, and children's own feces in Ghana and found food to be the primary pathway of fecal matter ingestion (Wang et al., 2017). These studies both use local *E. coli* contamination data and U.S. data on hand and object mouthing. A study of children in rural Bangladesh that used location-specific fecal contamination and mouthing data identified direct ingestion of soil and hand mouthing as primary pathways. At least three additional studies are currently exploring the pathways by which children are exposed to diarrheal pathogens and the relative contribution of each pathway:

1) The USAID Practices, Research, and Operations in Water, Sanitation, and Hygiene Activity (PRO-WASH), USAID Nawiri Program (Mercy Corps), and Innovations for Poverty Action are collaborating on a study in Turkana and Samburu counties of Kenya to identify transmission pathways of pathogens to children under 2 and community-preferred potential interventions to reduce transmission primarily in pastoralist communities. This study will inform USAID Nawiri WASH activities aimed at contributing to reductions in childhood acute malnutrition. Study results are expected in July 2022.

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[1] Though not the focus of this review, it is worth noting that there is active debate within nutrition and other sectors around the strengths and limitations of measuring stunting as an outcome, with ongoing discussion of alternative indicators for measuring chronic undernutrition and growth. See the following:

https://www.advancingnutrition.org/resources/stunting-considerations-use-indicator-nutrition-projects

https://www.advancingnutrition.org/resources/beyond-stunting-complementary-indicators-monitoring-and-evaluating-usaid-nutrition

2) USAID PRO-WASH, the USAID Fiovana project (ADRA), and Aquaya Institute are collaborating on a study in southeastern Madagascar to identify transmission pathways of pathogens to children under 2 and community-preferred potential interventions to reduce transmission. This study will inform USAID Fiovana (ADRA) WASH activities aimed at contributing to reductions in childhood chronic malnutrition. Study results are expected in May 2022.
3) The University of Iowa is working to develop and validate a model for predicting which social and environmental interventions appropriate for low-income, urban contexts (e.g., animal penning and building latrines, drains, or concrete floors) best prevent multi-pathogen transmission to infants in high disease burden countries using established Kenyan study sites as a model. The product of this study will be a virtual laboratory that nongovernmental organizations (NGOs)/other can use to input data and explore how shifting different types of conditions changes pathogen circulation patterns in peri-urban/urban settings.

Soil. Direct ingestion of soil by young children in low-resource contexts is common. Twenty-three percent of children <4 years old in rural Bangladesh were observed ingesting soil during the course of their daily activities (Kwong et al., 2021). In a five-hour structured observation, 18 percent of rural Bangladeshi children between 7 and 30 months of age were observed to eat soil (George et al., 2015), a context in which 97 percent and 14 percent of the households exhibited detectable *E. coli* and pathogenic *E. coli* in the soil, respectively. In a longitudinal study of 175 households in two rural locations in Njoro, Kenya, 37 percent of the children between 1 and 4 years old were observed occasionally ingesting less than a handful of soil, while 12 percent ingested a handful or more (Shivoga & Moturi, 2009). Children in high-income countries are estimated to ingest 9–135 dry milligrams (mg) of soil/day. In contrast, children in rural Bangladesh are estimated to consume 162–234 dry mg/day, with children placing their hands in their mouths accounting for 46–78 percent of soil ingestion and mouthing objects contributing 8–12 percent; direct ingestion of soil accounted for nearly 40 percent of soil ingested among children 6–23 months old. (Kwong et al., 2021)

Several studies have found that in rural areas of low-income countries, soil where children play around the household may be highly contaminated with fecal matter. In rural Bangladesh, 95 percent of soil samples were contaminated with *E. col*i, with a mean of 125,000 colony forming unit (CFU) *E. coli* per dry gram of soil (Ercumen et al., 2018a); of soil samples that contained any E. coli, 60 percent had one or more strains of pathogenic *E. coli* (Fuhrmeister et al., 2020). (In contrast, stored drinking water had 9.1 CFU E. coli per 100 mL.) In another region of rural Bangladesh, 97 percent of soil samples were positive for E. coli and 14 percent had one or more strains of pathogenic *E. coli* (George et al., 2016). A recent cross-sectional study in urban slums in Nairobi, Kenya, found diarrhea to be associated with caregiver-reported soil ingestion by IYC between three months and five years of age (Bauza et al., 2017). *E. coli* and human-associated *Bacteroides* fecal marker (HF183), enumerated with locally validated methods, were detected in 100 percent and 93 percent of soil samples, respectively, collected near each of the 54 households in the study sample (Bauza et al., 2017). Soil ingestion was also associated with diarrhea in children in rural Kenya (Shivoga & Moturi, 2009).

One observational study examined the effect of concrete flooring to replace dirt floors and reduce enteric infections. In a study of 2,755 urban Mexican households, concrete floors were associated with a 49 percent reduction in child diarrhea, 78 percent reduction in child parasitic infection, and 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 study did not examine children for bacterial or viral infections, the authors hypothesized that the health improvements were driven by reduced amoebic infections. The authors also noted that their conclusions that cement floors protect against diarrhea, parasitic infection, and anemia may not be generalizable outside of 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. One observational study in rural areas has found similar associations between improved flooring and improved child health outcomes, suggesting that there is a combination of building materials; water, sanitation, and hygiene infrastructure; and other factors such that the presence of improved flooring is associated 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,* but there was no association with infection of *Trichuris* or hookworm; the authors also noted a synergistic effect of deworming and finished flooring for infection with *Ascaris* (Benjamin-Chung et al., 2021).

Water. Fecal contamination of drinking water sources, including piped water sources, is widespread and affects an estimated 1.8 billion people globally (Bain et al., 2014). The risks of consuming contaminated water on child health are well documented (Wolf et al., 2018; Arnold & Colford, 2007).

By using more traditional fecal indicator tests as well as novel MST markers, a compelling picture was presented of the extent and mix of human and animal fecal contamination of water (among other fecal-oral pathogen transmission pathways) (Odagiri et al., 2016). In the cross-sectional study of 60 villages in Odisha, India, 74 percent of household stored drinking water (SDW) tested positive for thermotolerant coliforms, while 53 percent of SDW samples tested positive for Bacteroidales (Odagiri et al., 2016). The authors highlight significant animal fecal contamination (33 percent of samples) and human fecal contamination (19 percent of samples) of SDW. These findings further support the notion that the domestic environment is important for transmission of animal-sourced zoonotic pathogens in addition to human pathogens (Schriewer et al., 2015).

More than 50 percent of tubewells sampled contained detectable fecal contamination (measured by the total Bacteroidales fecal marker), with such specific pathogens as rotavirus, Cryptosporidium, and Giardia detected in between 8 and 15 percent of protected groundwater sources (Odagiri et al., 2016). Tubewells have long been considered among the safest of the groundwater sources because they are less susceptible to contamination than open wells, protected springs, or such unimproved surface water sources as streams, rivers, and ponds. It was also noted that increased village prevalence of child diarrhea in the six weeks following sampling conducted at each additional tubewell was detected with a tested diarrheal pathogen (Odagiri et al., 2016). More than half of the ponds in the study area exhibited domestic animal feces contamination, with this pattern persisting throughout the monsoon season (Daniels et al., 2015).

Hands. Children can be exposed to fecal contamination on their hands through mouthing contaminated hands or caregiver's hands contaminating food or water that a child later ingests. Hand and object mouthing is frequent and common among young children, particularly in low-resource settings (Kwong et al., 2016; Kwong et al., 2021). Both caregiver and child hands are often contaminated with fecal and enteric pathogens (Ercumen et al., 2017; Ercumen et al., 2018a; Ercumen et al., 2018b; Mattioli et al., 2015; Pickering 2010), which may result from activities such as toilet use, cleaning up child feces, sweeping, cleaning dishes, preparing food, and bathing (Pickering et al., 2011). Hand contamination of stored drinking water is supported by studies using Fecal Indicator Bacteria (FIB) (Mattioli et al., 2015, Pickering et al., 2010) and human and animal MST fecal markers in rural India (Schriewer et al., 2015). It is also supported by a study in Bangladesh that examined the impact of a safe drinking water storage container, which prevented hands from contacting the stored water. Use of the safe storage container alone reduced diarrhea by over 30 percent, and the additional use of chlorine did not create an added benefit (Ercumen et al., 2015). Despite the finding, dirty fingernails and fingertips have poor positive predictive value and negative predictive value with regards to the presence or absence of fecal contamination on hands (Parvez et al., 2019), visibly dirty caregiver hands have been associated with elevated levels of one of three markers of EED in a cross-sectional study of 216 children under the age of 30 months in rural Bangladesh (George et al., 2015).

Food. Foodborne pathogens caused 600 million illnesses and 420,000 deaths in 2010, primarily due to diarrhea caused by norovirus and *Campylobacter* (WHO, 2015). Fecal contamination can be introduced into food through contaminated water, hands, or utensils or result from cross-contamination from other foods (Motarejemi et al., 1993; Woldt & Moy, 2015). Food then offers an opportunity for pathogens to grow exponentially to infectious levels. Some bacteria, such as *Staphylococcus aureus* and *Bacillus cereus*, produce toxins while growing in food, resulting in foodborne intoxications or food poisoning.

Food fed to children to complement breastfeeding can be particularly risky because they tend to have high levels of moisture and warm temperatures - a hospitable environment for bacterial growth. In rural and urban Bangladesh, 18 percent of complementary food samples were contaminated with high levels of fecal coliforms (≥ 100 CFU/g of food), and 29 percent were positive for *E. coli* (Islam et al., 2012). Freshly prepared foods had lower FIB counts compared to foods saved for feeding later in the day, and E. coli and B. cereus counts increased with the duration of storage at room temperature for the leftover food. As in many other LMICs, most of the decline in height-for-age Z-score (HAZ) among rural Bangladeshi IYC occurs during the complementary feeding age (Saha et al., 2010). In a Tanzania study, FIB counts increased significantly for complementary foods stored longer than four hours, compared to freshly prepared food (Kung'u et al., 2009). In the Tanzania study, no drinking water source samples met the World Health Organization's guidelines for drinking water safety, and thus drinking water may have served as a source of contamination in the preparation of commercially fortified and instant porridge flours. In rural Bangladesh the mean contamination on both hands of a single child was 7.4 CFU/two hands (Ercumen et al., 2018a), so even if children used their hand to eat, dirtied their hands, and then used their hands to eat again before cleaning their hands, the amount of contamination within the food itself would be substantially higher than that transferred through hand-to-mouth feeding.

There are very few studies on household-level interventions to improve food hygiene in low-resource settings. One such study in Nepal implemented an intervention that included local rallies, games, rewards, storytelling, drama, competitions linking with emotional drivers of behavior, and "kitchen makeovers" to increase five target behaviors: cleanliness of serving utensils, handwashing with soap before feeding, proper storage of cooked food, thorough reheating of cooked food, and water treatment. Six weeks after the intervention, 43 percent of intervention households (compared to 2 percent of control households) practiced all five target behaviors. The study did not report the level of fecal contamination in complementary food before and after the intervention (Gautam et al., 2017).

Flies. Flies that carry fecal contamination picked up from feeding on feces can transfer this fecal matter to food (Islam et al., 2012; Kung'u et al., 2009; Afifi et al., 1998). A study in rural Bangladesh found a linear relationship between *E. coli* contamination in flies and children's stored food from the same household (Doza et al., 2018). Fly density has been associated with diarrhea (Collinet-Adler, 2015; Cohen et al., 1991; Fotedar, 2001; Hald et al., 2004; Holt et al., 2007), and fly control programs have successfully reduced reported diarrhea (Chavasse et al., 1999).

Fomites. Fomites are inanimate objects that can serve as vehicles of disease transmission. A few studies have examined objects in the home for their potential to transmit fecal contamination due to children's object mouthing (Kwong et al., 2016, 2020a, 2020b; Stanton & Clements, 1986; Vujcic et al., 2014). Fomites' potential role in fecal transmission is based on the assessment of sentinel objects (often non-porous plastic balls) placed within the house to serve as a proxy for general household contamination (Ercumen et al., 2018b; Keshav et al., 2015; Huda et al., 2018; Vujcic et al., 2014). Since these plastic balls have different surface properties than many of the objects children may put in their mouths, they may under- or overestimate children's exposure through object mouthing. Nonetheless, they provide an insight into potential levels and prevalence of contamination. While cross-sectional studies found significantly lower contamination on study-provided sentinel toys in households with improved sanitation and no visible feces (Huda et al., 2018; Vujcic et al., 2014), a randomized controlled trial in

Bangladesh found no significant difference in the level of fecal contamination between households with improved WASH infrastructure and those without; fecal contamination was found on 76–81 percent of sentinel toys (Ercumen et al., 2018b). In addition to mouthing of toys, touching and mouthing of cloth may also serve as a pathway for fecal transmission (Stanton & Clements, 1986; Hoque et al., 1995). In Bangladesh, children who were observed putting visibly dirty objects in their mouths had lower scores on the Extended Ages and Stages Questionnaire used to measure child development (George et al., 2021a and 2021b).

Relative Importance of Each Pathway. Interventions to interrupt the transmission of fecal contamination typically focus on water treatment and provision, the use of household sanitation, and handwashing (see Cairncross et al., 2010; Luby et al., 2018; Null et al., 2018). In settings heavily contaminated with feces, interventions may have had limited effects on reducing diarrhea or improving growth because they did not sufficiently reduce exposure to feces (Clasen et al., 2012; Null et al., 2018). It is possible that a substantial degree of fecal transmission continued along pathway(s) that were targeted by interventions, or that the interventions did not target pathways responsible for the primary pathways of transmission (Kwong et al., 2021).

Understanding the degree to which different fecal transmission pathways contribute to a child's ingestion of fecal matter can help prioritize pathways for intervention. Three studies have compared two or more pathways of exposure to identify which primarily contributes to children's overall intake of fecal matter (Mattioli et al., 2015; Wang et al., 2017, Kwong et al., 2021). In a study that explored the hand mouthing and drinking water pathways in rural Tanzania, 99.7 percent of children's exposure was due to contacts between the child's hand and mouth while only 0.3 percent of exposure was from ingestion of drinking water (Mattioli et al., 2015). In urban Ghana, ingestion of water, food, and soil; hand-to-mouth contact; and flies were all investigated as potential pathways of fecal transmission. The authors identified food as contributing 99 percent of children's fecal intake (Wang et al., 2017). However, due to a lack of data on hand-to-mouth and object-to-mouth exposures among children in low-income communities at the time these studies were published, both used hand- and object-mouthing frequencies and other data collected from children in the U.S.

A study from rural Bangladesh that used local data for both levels of environmental contamination and children's exposure revealed that the primary pathways of E. coli ingestion vary by child age and that children >6 months old ingest 10 times more E. coli than younger children (Kwong et al., 2020). Among children <6 months, placing objects in the mouth accounted for 60 percent of ingested *E. coli; and additional 20 percent was from directly ingesting soil and 15 percent from mouthing their own hands*. For children 6–11 months old, the primary pathways were mouthing their own hands (33 percent), directly ingesting soil (31percent), and mouthing objects (16 percent), with direct ingestion of feces contributing 9 percent and eating contaminated food providing 6 percent. The contribution of contamination from food was substantially higher for children older than 1 year. For children 12-23 months old, the primary pathways of E. coli ingestion were mouthing their own hands (32 percent), ingestion of contaminated food (27 percent), and direct soil ingestion (24 percent). This was similar to children 24-35 months old, except that a primary pathway of E. coli ingestion was mouthing of objects rather than direct soil ingestion. The modeled amount of *E. coli* ingested by children and the predominant pathways of *E. coli* ingestion were unchanged by the WASH interventions implemented in the WASH Benefits trial (water: distribution of a safe storage container and point-of-use water treatment tablets; sanitation: construction of a dual-pit latrine and provision of and encouragement to use a child potty and sani-scoop for animal feces; hygiene: construction of handwashing stations near the kitchen and latrine and handwashing promotion) (Kwong et al., 2021; Luby et al., 2018).

3.0 RECENT STUDIES ON INTERVENTIONS TO INTERRUPT CONTAMINATION PATHWAYS

This section reviews the range of interventions being tested to improve hygienic environment for IYC by interrupting one or more of the contamination pathways outlined in the previous section. The interventions are playmats/playpens, poultry cooping, safe disposal of infant and child feces, and improved flooring.

It should be noted, however, that since publication of the HE literature review (USAID, 2018), the findings from several large, multi-faceted randomized control trials (RCTs) were published (WASH Benefits [Luby et al., 2018; Ercumen, 2018a; Ercumen et al., 2018b, Null et al., 2018]; Sanitation Hygiene Infant Nutrition Efficacy Trial [SHINE] [Rogawski McQuade et al., 2020, Gough et al., 2019). The lack of individual and synergistic impact of these integrated WASH-nutrition interventions spurred intensive debate in WASH and nutrition sectors, specifically to better understand why WASH as implemented in the RCTs did not have the anticipated impact on reducing IYC exposure and thus on improving IYC health and growth. The lack of area-wide sanitation and community water supply across all RCTs was specifically identified as inadequate to interrupt infant-specific fecal-oral pathways. In addition, authors and other commentators suggested that the set of interventions failed to reduce ambient feces from the infant-specific sources and pathways elaborated in earlier sections of this review—soil, infant, and animal feces in particular. Pickering et al. (2019a) conclude that "despite achieving substantial behavioral change and significant reduction in infection prevalence for some enteric pathogens, detection of enteropathogens among children in the WASH groups of the trials was typically at ten times higher prevalence compared with high-income countries." They suggest that "future research in the WASH sector focus on developing and evaluating interventions that are radically more effective in reducing fecal contamination in the domestic environment than the interventions implemented in these trials." Many of the study authors suggest that "transformative WASH interventions are needed that are more efficacious in interrupting fecal-oral microbial transmission in children living in highly contaminated environments" (Rogawski McQuade et al., 2020). Authors define these as interventions that radically reduce fecal exposure (Makasi & Humphrey, 2020) and "encapsulate the guiding principle that—in any context—what is needed is a comprehensive package of interventions tailored to address the local exposure landscape and enteric disease burden" (Cumming et al., 2019).

3.1 PLAYMAT/PLAYPEN

Research on Playmat/Playpen Interventions. A number of studies exploring aspects of playpen and playmat use as an option for improving the hygienic environment of IYC have been published since the 2018 review. These include studies on playpens with walled perimeters (which potentially reduce exposure by restricting animals from sharing the space with IYC and constraining infants to a bound space that allows caregivers to more easily maintain hygiene and monitor infant exploratory mouthing). The team has included these in Table 1 along with shorthand titles used in the discussion that follows.

The results demonstrate it is unlikely playmats and playpens meaningfully contribute to reducing infant exposure to fecal contamination or enteric pathogens, and if the projected reduction is sizeable enough to impact health and growth. With the exception of the Bangladesh Drowning Cohort Study, all studies had relatively small sample sizes (9–179) and included use of the Trials of Improved Practices (TIPS) method to investigate the various aspects of use and potential for the intervention to reduce fecal exposure. TIPS engage participants over time to develop and test possible behavioral improvements, often involving a behavior-enabling product. Some studies used imported playpens while others engaged users to help design playpens that were locally produced; two used a combination of playpen models. This user-centered design strategy attempts to incorporate the desired attributes of rural farm families, address future accessibility and affordability when playpens are not supplied to families, and maximize the potential to scale up. All of the playmats tested were locally produced. Some of the studies complemented the TIPS method with rigorous observation (WASHPaLS Amhara TIPS, Sidama TIPS, Zambia TIPS, SHINE Sub-study), 24-hour recall of use (WASHPaLS Amhara TIPS, Zambia TIPS), and/or microbiological measures (WASHPaLS Amhara TIPS, Ethiopia Feasibility RCT).

Table 1. Playpen Studies Discussed in this Review, with Shorthand Titles of Reference

Playpen Studies					
Authors (and link)	**Shorthand Title**	**Location**	**Age**	**Sample size**	**Type(s) of Playpen**
Alonge et al. (2020)	Bangladesh Drowning Cohort Study	7 rural sub-districts, Bangladesh	9–47 months	45,460; 5,981 playpens only	86% wooden 14% plastic Locally produced (no mention of UCD*)
Rosenbaum et al. (2021)	WASHPaLS Amhara TIPS	Rural Amhara, (Northern) Ethiopia	7–12 months	31	2 local UCD* 1 imported nylon
Budge et al. (2021b)	Sidama TIPS	Sidama, (Southern) Ethiopia	10–18 months	9	3 local UCD*
Budge et al. (2021a)	Ethiopia Feasibility RCT	Sidama, (Southern) Ethiopia	10–18 months 10.6 mo. average	100	1 local UCD*
Reid et al. (2018)	Zambia TIPS	Rural Zambia	6–24 months	21	1 large UCD* community structure 1 imported plastic
Fundira (Dissertation) (2019)	SHINE Sub-study	Rural Shurugwi and Chirumanzu, Central Zimbabwe	18.7 mo. average	179	1 imported plastic Locally produced playmat
* *UCD = User-centered design involving community member/participants in the local design of playpen.*					

Playpens: Feasibility and Acceptability. Several studies have explored feasibility and appeal of playpen use and playpen value, as well as caregiver perceptions of changes in infant exploratory mouthing, geophagy, infant cleanliness, and direct consumption of animal feces. Feasibility and appeal were measured by reported use, perceived benefits, assessed value, and other factors. Four of the studies (Zambia TIPS, WASHPaLS Amhara TIPS, Sidama TIPS, and the Ethiopia Feasibility RCT) documented that caregivers considered playpens both feasible and appealing to use. Caretakers in these studies cited numerous hygiene, health, and non-health benefits for both infants (such as keeping child from harm, less consumption of dirt and feces, keeping child and clothes cleaner, accelerated motor development, protection from smoke and flame) and benefits for caregivers themselves (such as reduced physical burden of carrying the infant, reduced worry, more time for chores, less laundry). Additionally, studies that assessed family support for the intervention found that study participants said their families supported them using playpens with little or no objection (WASHPaLS Amhara TIPS, Sidama TIPS, Ethiopia Feasibility RCT, Zambia TIPS). The Ethiopia Feasibility RCT also documented caregiver perceptions that God approves of their use of the playpen.

While the WASHPaLS Amhara TIPS, Ethiopia Feasibility RCT, and Sidama TIPS documented family and community approval and appeal of the playpens, the Zambia TIPS found community reactions a barrier to use of both the imported plastic and larger locally built playpens (despite approval from immediate household members). A few of the studies noted that a small number of IYC just don't like being in the pens, and many required toys and/or a sibling to entertain them while inside. The WASHPaLS Amhara TIPS showed households valued the playpens and chose them over cash payments when offered a choice at the close of the study between keeping the playpen or receiving a cash equivalent value of $17 USD.

Model A, an imported playpen, is lightweight, easily disassembled and portable, with five net sides and one nylon side panel with a zipper-closed door.

Model B, a locally designed playpen, is 1.5 meters square with 3 net sides and 1 canvas side with door (opened/ closed with an extra-large button/string wrap closure), and a removable net canopy top.

Model C, a locally designed playpen, is 1.5 x 1.1m rectangular with 2 net sides and 2 spinning bottle walls for child stimulation, and 2 cm foam padding.

Figure 1. Three playpens tested in the WASHPaLS Amhara TIPS include one low-end imported and two locally designed models

Findings across several of the studies documented how caregivers used the playpens while carrying out a range of tasks inside and outside of the home. The WASHPaLS Amhara TIPS also documented women using the playpens with infants while socializing with visitors to the home. Risky conditions and infant behaviors are documented outside the playpens, with some contamination risk noted inside the playpens, including multiple older children and animals in the playpens with (and sometimes without) the infant, and visibly unclean objects in the playpens with infants. The WASHPaLS Amhara TIPS documented some changes in childcare practices, specifically care shifting from mother to older siblings or grandmothers while the IYC were in the playpen. The Bangladesh Drowning Cohort Study was a large-scale, before-and-after cohort study estimating the impact on drowning rates of community-based childcare centers and household playpens: 116,054 children aged 9–47 months were exposed to the intervention package, and playpens were provided to 45,460 of those children (5,981 received playpens only, without the rest of the intervention package). This published study provides little documentation besides overall use of the playpen and statistical analysis of separate and combined playpen and childcare interventions on drowning.

Several of the studies documented frequency and/or duration of use and other variables (SHINE sub-study; Zambia, Sidama, and WASHPaLS Amhara TIPS; and Ethiopia Feasibility RCT). Most studies measuring reported use noted it was difficult for respondents to estimate time, so there is some doubt on the reliability of those measures, and studies measured and analyzed time differently, so they cannot be easily compared. Three of these studies reported frequent and often daily use of playpens. The WASHPaLS Amhara TIPS reports average use of just over two hours in the previous day, with time decreasing slightly from the one-week to the three-week recall exercise. Caregivers reporting using playpens for an average of 2.4–3 instances on the day before each of the recall exercises. The Sidama TIPS study elicited at study enrollment a commitment to use the playpen for six hours a day and then subsequently documented time use that ranged between 2.5–6 hours a day among the nine TIPS participants. The Bangladesh Drowning Cohort Study reported poor compliance with the use of the playpens, without specifying the duration of time used each day Follow-up surveys and home visits showed that 84 percent of the 5,981 who received only the playpens were not using them during 8–9 out of 10 home site visits, on average. Out of those not using their playpen, 75 percent reported that the children do not like to stay inside the playpen. The study cohort was notably older than the others, ranging from 9–47 months, with the older end of the cohort considered too old for a playpen by international child development recommendations. No negative consequences of use were observed or reported, again with the exception of the Bangladesh Drowning Study, which found that the age-adjusted cumulative incidence of drowning was higher in the playpen-only and playpen + creche groups than at baseline. In the Ethiopia Feasibility RCT, random visits document 41 percent of infants were found in the playpens when researchers entered the household. Findings around appropriate use and cleaning were mixed across the four-week study duration, with appropriate use measured at 48 percent and cleaning at 56 percent.

The Zambia TIPS reported that both the private, mobile, relatively small, imported plastic playpen and large, fixed, outdoor community play space were used for similar durations, ranging from 10 minutes to three hours a day; average time use was not reported. Based on this publication, the average use episodes varied between 2 and 4.2 hours/day (at different recall exercises and for community and smaller household playpens), but the range of use episodes across households are not reported. In the SHINE trial, playpen use was observed in only 10 percent of the intervention households and used only twice on average during the six-hour observation period. Total times in the playpen were not reported. The authors suggest that the advanced age of the study infants (18 months) likely affected use, with speculation that use would be higher at earlier ages when playpens might better accommodate young infants. While the SHINE intervention (that included both conventional WASH and BabyWASH elements, including playmats and playpens) resulted in fewer children ingesting soil (52% in WASH compared to 70% in non-WASH arms), the authors did not attribute this reduced geophagy directly to the playpen. At the same time, none of the recall exercises asked where the infant would have been if not in the playpen, so the team can only speculate whether they would have been on or off the dirt floor, strapped to a caregiver's back, or in some other location.

Playmats and Playpens: Qualitative Reduction in Exposure. In addition to the amount of time that a child spends in a playpen, the ability of a caregiver to maintain the cleanliness of a playpen influences the degree to which playpens can reduce children's exposure to fecal contamination. Caregivers reported regular cleaning and maintenance of playpens (WASHPaLS Amhara and Sidama TIPS and Ethiopia Feasibility RCT), although the Ethiopia Feasibility RCT used barrier analysis, documenting that the cost of cleaning materials was a main barrier to this practice. The Zambia TIPS documented more generally that cleaning maintenance was a barrier to use, as well as women's increased burden to clean the larger community play space. The WASHPaLS Amhara TIPS measured *E. coli* on household floors and playpens three weeks after placement in homes and found many (18/23) had culturable *E. coli* despite reports of periodic (at least once a week) cleaning. Six of 23 playpens were contaminated at counts below 0.1 CFU/cm^2, and all but two of the 23 playpens were <1.0 CFU/cm^2. By comparison, 10 of 23 sampled floors were contaminated at the maximum detection limit of 4.26 CFU/cm^2. (For reference, the area of the playpen models ranged from 16,500 cm^2 to 22,500 cm^2.) That study also documented occasional observations of chickens in and around the playpens themselves and one instance of poultry feces on a playpen. *E. coli* counts from playpens were greatly reduced compared with the floors on which infants might otherwise be placed, but key to note that playpen had only used in situ for about three weeks and are being compared to floors that had E. coli build up over time. Given regular but suboptimal cleaning practices of household, playpen contamination would likely increase 'some' over time.

Playmat/Playpen: Impact on Environmental and/or Child Health Outcomes. Results of the full SHINE trial and a focused analysis of the playpen data suggest neither the playmat nor playmat/playpen options by themselves or in combination with the full WASH intervention reduced enteropathogens or pathogen-attributable diarrhea (Rogawski McQuade et al., 2020), despite the extensive formative research (Ngure et al., 2013; Mbuye et al., 2015) and high intervention fidelity (Humphrey et al., 2019). The Ethiopia Feasibility RCT documented reduced odds in reported diarrhea of the cohort of infants in the playpen (OR 0.57, 95% CI 0.40−0.83), but no reduction in odds of *Campylobacter* in stools. The Bangladesh Drowning Study explored use of playpens as an option to reduce drowning rather than other outcomes such as reduced pathogen exposure. That study found no reduction in mortality with playpen alone or in combination with community daycare (and these groups *may* have had a higher risk of drowning. The Bangladesh study did find that daycare centers or 'creches' are highly protective in preventing childhood drowning in rural Bangladesh for children above age 1-year and should be considered for further scale-up).

Interventions that Incorporated Playmats/Playpens but Did Not Evaluate Environmental or Child Health Outcomes. In addition, some implementers have incorporated playmat and playpen interventions without the supporting evidence base, and a subset of those are contributing the evidence base through project monitoring evaluation. In Ghana, a playmat was a key WASH behavior in the Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) "WASH 1,000 Program." However, data on design, acceptability, and use were not collected, nor were data on bacterial/fecal contamination or infant health outcomes. As part of the USAID Empowering the New Generation to Improve Nutrition and Economic Opportunities (ENGINE) Project (2011–2016), a small study investigated the market potential of subsidizing polyvinyl chloride playmats, marketed through micro-enterprises and local women's saving groups. Almost 4,000 mats were sold, and most households (77%) reported always using the mat for the intended purpose. However, informal follow-up indicated many mats had tears after a short time, and they were ineffective when infants became mobile (Save the Children, personal communication). The follow-on project, USAID Growth through Nutrition, encouraged use of do-it-yourself playmats but chose *not* to include playmats in their selected market-based WASH products primarily because market viability had not been demonstrated (USAID, 2021b). An informal survey of the CORE Group and PRO-WASH[2] partners identified several organizations promoting the use of playmats for improving health and nutrition outcomes of IYC. These include World Vision Kenya and Uganda promoting use of playmats through care groups (evaluation data pending) and Global Communities conducting a five-arm RCT in the Lake Zone of Tanzania to measure integrated nutrition/parenting interventions, including playmats, on a range of health and growth outcomes (pending).

Playmats/Playpens: Takeaways. Playmats and playpens were generally considered feasible and acceptable and provided multiple benefits to caregivers, as documented in studies that measured these variables. However, frequency and duration of use varied across the studies with a range between 10 and 360 minutes/day of use in those studies that measured duration. Since there currently exists no data on dose-response relationship for pathogen infection among children in low-income countries, it is currently unclear if removing IYC from the environment outside the playpen for several hours a day has impact on morbidity or growth. It is also unclear if time spent in the playpen replaced time on a

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2 CORE Group's (https://coregroup.org/our-work/working-groups/) membership is comprised of 180+ organizations advancing community health in LIMCs. PRO-WASH (https://www.fsnnetwork.org/PRO-WASH) is an initiative funded by USAID's Bureau for Humanitarian Assistance providing support to USAID implementing partners to strengthen the quality of WASH interventions through capacity strengthening, knowledge-sharing and applied WASH research opportunities.

presumably contaminated dirt floor, or if the IYC would have otherwise been strapped to their caretakers' backs, where access to soil, feces, and contaminated objects were more limited.

With current data, we see no plausible basis to suggest playmats and playpens alone will be protective of child health or growth. The WASHPaLS Amhara TIPS concluded that playpens alone are not effective as a barrier against pathogen transmission but may be part of a multi-faceted solution. The other three conclude playmats and playpens may reduce children's exposure to fecal matter, but more research is required to determine if the degree of reduction is clinically significant (Sidama TIPS, Ethiopia Feasibility RCT, Zambia TIPS). Other studies do not directly address the viability of the playpen option to improve hygienic environments (only reporting their specific study findings).

3.2 POULTRY HUSBANDRY

Research on Poultry Husbandry and Feces Management Interventions. Relatively few studies have examined the effect of poultry husbandry and feces management on fecal contamination of the environment and enteric disease. An RCT in a Peruvian shantytown randomized half of households (n = 27) to receive chicken coops donated by the project and half (n = 28) to receive no intervention (but those who had coops could continue to use them) (Oberhelman et al., 2006).

In three rural and one urban African context, Helen Keller International implemented an "Enhanced Homestead Food Production" program that included training to improve backyard poultry raising (Nordhagen & Klemm, 2018). Communities received training on (a) preparing nutritious feed using local ingredients, (b) making a coop/henhouse from local materials, (c) taking measures to prevent and control disease, (d) improving egg production, and (e) separating children from animals. Some projects provided chicks, arranged vaccinations, or money or materials for the construction of coops.

WASHPaLS funded two grants, one conducted by International Centre for Diarrheal Disease Research, Bangladesh (icddr,b) and the other conducted by The Water Trust in Uganda, to evaluate interventions to reduce children's exposure to poultry and poultry feces. In Bangladesh, icddr,b conducted formative research to identify local strategies to separate children from poultry and poultry feces and then designed a neighborhood-based behavior change intervention promoting improved nighttime poultry housing practices and poultry feces management. icddr,b implemented a small-scale trial in four villages, with the primary outcome being the percent of households that confined all poultry outside the house at night. The two-arm study involved two villages that received a Neighborhood-based Environmental Assessment and Planning (NEAP) behavior change intervention and subsidy (n = 38 households) and two villages that received the behavior change intervention only (n = 42 households). Formative research suggested that material and labor costs were a major constraint to building improved poultry housing, so households in one arm received a subsidy of approximately 23 USD (43% of the average cost of a multi-compartment shed with ventilation). The NEAP intervention incorporated principles of household-based assessments and multiple levels of behavioral determinants and included group meetings and household visits with poultry raisers (all of whom were women), group meetings with male members of enrolled households, and a training session with local masons (USAID and Water Trust, 2021).

In Uganda, The Water Trust aimed to increase poultry production through the establishment of brood chambers. They also sought to increase both daytime and nighttime chicken cooping. The Water Trust conducted a large-scale (n = 1,305 households across 51 communities) RCT to evaluate the four-day triggering and training program, monthly coaching visits, and the use of self-help savings groups to support the construction of new infrastructure and purchase of additional animals. The skills training focused on increasing economic returns from poultry raising in a hygienic manner and affordable practices such as construction or use of a standalone chicken house, chicken run (or fenced in outdoor area), footbath, handwashing facility, chicken feed, synchronized hatching, and chicken brooders and treating sick chickens, vaccinating most or all chickens, separating sick chickens, or sweeping up chicken feces. Men and women from the same household were invited to participate, but often only one household member attended the training; 59 percent of the trainees were women. Loans from the self-help groups were not available as expected due to COVID-19 disruptions, so the project offered to provide eligible groups loans for approximately USD134 or USD269. Fifty-three percent of the 51 groups were ineligible or not interested, primarily because they were concerned about their group's ability to repay the loan. The impact of the loan was not evaluated before the end of the study (USAID and icddr,b, 2021).

Poultry Coops: Feasibility and Acceptability. The feasibility and acceptability of the interventions are partly indicated by their uptake. Of 55 households in the Peruvian study, two were non-compliant and replaced; no other indicators of uptake were reported (Oberhelman et al., 2006). Uptake also was not reported in the Helen Keller study. While the poultry-focused components of Helen Keller International's program were not fundamentally "unacceptable," there was relatively low uptake of the behavioral recommendations because women lacked decision-making power and/or behavior change communication (BCC) needed to be strengthened. The intervention created little to no increase in the percent of households practicing both daytime and nighttime confinement or the practicing only nighttime confinement. These indicate that the project elements were not as feasible, acceptable, or comprehensive as they could have been.

icddr,b conducted over a year of formative research to identify intervention components that would be feasible and acceptable. No study households had an improved poultry shed at baseline. By endline, 87 percent of subsidy households and 33 percent of non-subsidy households had built a multi-compartment, ventilated poultry shed. While the intervention was successful, some constraints identified by the project were 1) the cost of labor and the durable materials, 2) construction of a multi-compartment shed requires a skilled mason, 3) some households do not have space for a shed, 4) shed size depends on flock composition, which is variable. Poultry-raisers also expressed concern that confining poultry in a corral during the day could also result in them overheating or being caught in the cold, rain, and mud if there weren't sufficient raised platforms or covers.

In Uganda, the training received by participants in the intervention arm emphasized that hygiene behaviors such as sweeping up feces and constructing a chicken corral were relatively inexpensive if households used local materials. However, discussions with households that did not build corrals revealed that they perceived that corrals only made sense if there was a chicken shed in the middle, but they had difficulty sourcing natural materials to build the sheds and did not have or want to spend the money necessary to purchase the materials (USAID and icddr,b, 2021). Depending on the design of the chicken shed, typical costs would range from USD30–USD40 for mud, wattle, poles, grass/thatch, fish net [for chicken run] to $100–$160 for chicken houses that appealed most to householders [i.e., made with iron sheet and brick]. In both Bangladesh and Uganda households expressed concern that if poultry were confined during the day then they would need to be fed.

Poultry Coops: Reduction in Exposure. As a proxy for reduction in exposure, icddr,b examined whether having an improved shed enabled poultry raisers to house their poultry outside the household dwelling. In Bangladesh, households with an improved poultry shed were more likely to confine poultry separate from people at night. Households with an improved poultry shed also had fewer poultry feces piles inside the household dwelling, although the difference was small and not significant (USAID and Water Trust, 2021). After the intervention, households were more likely to confine all poultry outside, have an improved poultry shed, have no feces inside the household dwelling, and have a specific place for disposing of poultry feces. Among all study households, the proportion of households reporting that they confined all poultry outside the household dwelling the previous night was significantly higher at endline (33%) than at baseline (2.5%). Of those study households that built an improved poultry shed, 47 percent still confined some poultry inside during endline. However, a considerably higher proportion of study households (81%) had no visible poultry feces inside the household dwelling at endline compared to baseline (54%). Similarly, a significantly higher fraction of primary poultry raisers reported washing hands with soap after handling poultry feces or other animal feces, or after feeding poultry or handling poultry or poultry products. At endline, 58 percent of households reported using a specific place for disposing poultry feces compared to 30 percent baseline. Households in both study arms built improved sheds, but households receiving a monetary subsidy were more likely to build an improved poultry shed within the three-month intervention period than those households that did not receive a subsidy (USAID and Water Trust, 2021). These findings suggest that, with or without subsidies, an intensive behavior change campaign based on extensive formative research can (at least in the short term) shift behavior expected to reduce children's exposure to fecal matter.

In their Uganda study, The Water Trust found no qualitative reduction in exposure to poultry or poultry feces. Among control households at baseline, poultry feces were observed in 28 percent of households, 84 percent of households reported allowing their poultry to roam free during the day, and 12 percent reported keeping their poultry in a dedicated space at night. Households in the treatment arm were no more or less likely to have an observed poultry shed, observed free-roaming poultry, or observed poultry feces in the compound, and they were no more or less likely to report handwashing after handling animal or animal feces or spending any time managing poultry on the prior day. There was also no difference in the number of eggs sold or consumed or the number of chickens consumed. Of the indicators collected on poultry feces risk perceptions and management self-efficacy, the only significant difference was that more households in the *control* arm (43%) reported no difficulty corralling poultry than households in the intervention arm (30%) (USAID and icddr,b, 2021).

Poultry Coops: Impact on Environmental and/or Child Health Outcomes. In the randomized controlled trial in Peru in which half of households received a chicken coop (Oberhelman et al., 2006), children <5 years old in the chicken coop arm had twice the incidence of diarrhea caused by Campylobacter compared to controls and seven times the incidence of controls with more than 20 chickens, while rates of asymptomatic Campylobacter infections were similar. The authors theorize that in households without coops, children primarily acquired Campylobacter outside the home, whereas in houses with coops, coops were close to home and increased the incidence of Campylobacter acquired at home.

An evaluation of Helen Keller International's Enhanced Homestead Food Production program found that uptake of behavioral recommendations for improved poultry hygiene was low, egg productivity did not increase, and egg consumption was low, though egg consumption was higher in families that had chickens than those that did not (Nordhagen & Klemm, 2018). Women were in charge of raising poultry but not necessarily in charge of the profit earned by selling poultry-derived goods.

The icddr,b study did not evaluate the effect of the intervention on environmental or child health outcomes. The Water Trust study found no significant difference in the prevalence of child hand rinse samples that had any detectable *E. coli* (treatment arm: 57% prevalence; control arm: 49% prevalence). Among children in the control arm, the caregiver-reported seven-day prevalence was 17.8 percent for diarrhea, 44.8 percent for respiratory infections, and 30.2 percent for malaria. There was no significant difference in the seven-day prevalence of caregiver-reported diarrhea, respiratory infections, or malaria, with the difference in prevalence between arms ranging from 2 to 4 percentage points (USAID and icddr,b, 2021).

Poultry Coops: Takeaway. A large-scale observation study in Ethiopia found that children in households that raised backyard poultry were healthier than those that did not keep chickens, but that those who kept chickens inside their house at night were less healthy than those who did not keep chickens at all (Headey & Hirvonen, 2016). This suggests that the focus of poultry interventions should be on preventing chickens from sleeping inside the same dwelling where the child sleeps at night. This can be accomplished through the use of chicken coops constructed sufficiently far from the house and

BCC that supports the agency of women (who are typically in charge of raising poultry) to make or share in decisions regarding poultry confinement structures, vaccinations, and the money and eggs that result from poultry-raising. In Peru, chicken coops were installed just outside the front door of participating households and these households experienced twice the incidence of symptomatic Campylobacter infection. Coops located far from the house may be useful but in this case coops within easy access of a child increased diarrhea. The Helen Keller project concluded that 1) increasing egg consumption requires strong BCC, 2) programs should focus on improved practices rather than improved breeds of poultry, and 3) effectively supporting women's chicken production efforts also requires supporting women's decision-making capacity. Building on the conclusion that explicit conversations about responsibilities and decision-making needed to be part of the intervention, icddr,b's NEAP intervention included male engagement sessions that discussed not only the intervention but also male-female and household dynamics related to the intervention.

Poultry-raising practices were significantly altered among study households participating in icddr,b's NEAP intervention . In both subsidy and non-subsidy arms of the study, it successfully encouraged poultry-raising households to build improved poultry sheds, confine poultry outside of household dwellings at night, reduce/prevent poultry feces in household dwellings, and dispose of poultry feces in a dedicated location (USAID and Water Trust, 2021).

However, if household members are not convinced that small changes will have an impact, they may be reluctant to make any change at all. The Water Trust RCT found that despite training messages emphasizing that several key poultry management practices (such as an outdoor chicken run made of poles and netting) could be done at very little cost, there was significant resistance to undertaking these changes in the absence of a chicken house, which is a dedicated enclosure with walls, a door, and a roof that requires substantially greater financial investment.

The projects in both Bangladesh and Uganda found that even households that have dedicated spaces for poultry only (including chicken houses and fenced-in outdoor spaces for poultry, coops, and baskets) still have high rates of observable poultry feces, likely connected to traditional poultry feeding practices that allow for free-roaming animals. A key underlying challenge is that rural households are managing poultry at a scale that may be too small to justify investing in appropriate facilities and recurring food and immunization expenses given the significant risks for poultry (i.e., death by predation or disease or theft). Yet backyard chicken rearing is still at a scale large enough to pose a significant health risk for children under five (USAID and icddr,b, 2021).

3.3 SAFE CHILD FECES MANAGEMENT

Research on CFM Interventions. Two small, multi-phased studies, one in India and another in Bangladesh, identified the most influential factors (behavioral determinants) of CFM behaviors, used user-centered design (UCD) to develop locally produced enabling technology options, and incorporated a determinant-oriented intervention on improved CFM.

The promotion of behavioral recommendations together with the enabling technologies in Bangladesh (Huda et al., 2021) improved caregiver knowledge about safe defecation and the hygienic practices of children and led to improved reported latrine use of IYC. The study reports caregivers described reduced burden and related time savings of disposing of children's feces, while preparing and motivating caregivers to build regular and proper latrine use.

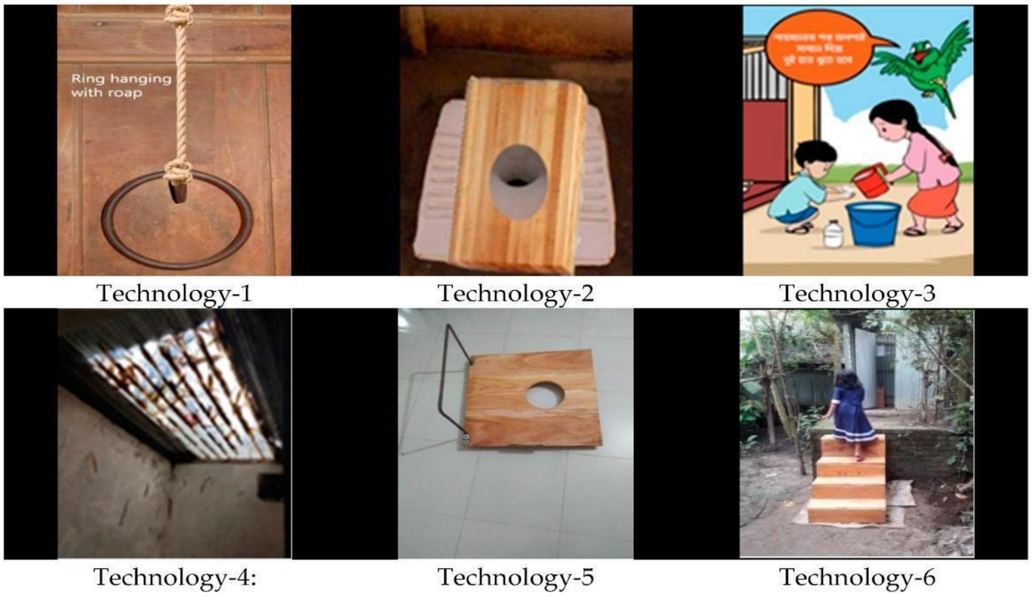


Figure 3. Enabling technologies from the two trials of improved practices. *1) Iron ring hanging with rope inside the latrine to hold while squatting; 2) Wooden seat placed on the pan to reduce the distance between children's feet while squatting; 3) Cartoon image with hygiene message to attract children inside the latrine; 4) Transparent fiberglass roof tile to address children's fear of the darkness; 5) Wooden seat with the handle placed on the pan to make children sit comfortably; 6) Stair to facilitate latrine access.*

One of the WASHPaLS small grants funded the Indian NGO Gram Vikas, working with Emory University and the University of Zurich, to explore how a combined community and household-based intervention including enabling technologies impacted caregiver CFM behaviors. Novel and low-cost hardware to facilitate safe feces disposal and reduce identified barriers were developed as part of the program design and piloting, following an UCD approach. The intervention focused on two CFM behaviors of interest: safe disposal of child feces and child latrine training. Target participants were primary caregivers of children <5 years old, oftentimes the mother of the child. However, other household members and secondary caregivers, such as fathers and grandmothers, were also engaged during certain activities.

Using the Risks, Attitudes, Norms, Ability, and Self-Regulation (Mosler, 2012) approach to behavior change, the formative research systematically identified the most influential determinants of the behaviors of interest, safe disposal of child feces, and child latrine training and integrated those into five household and community activities.

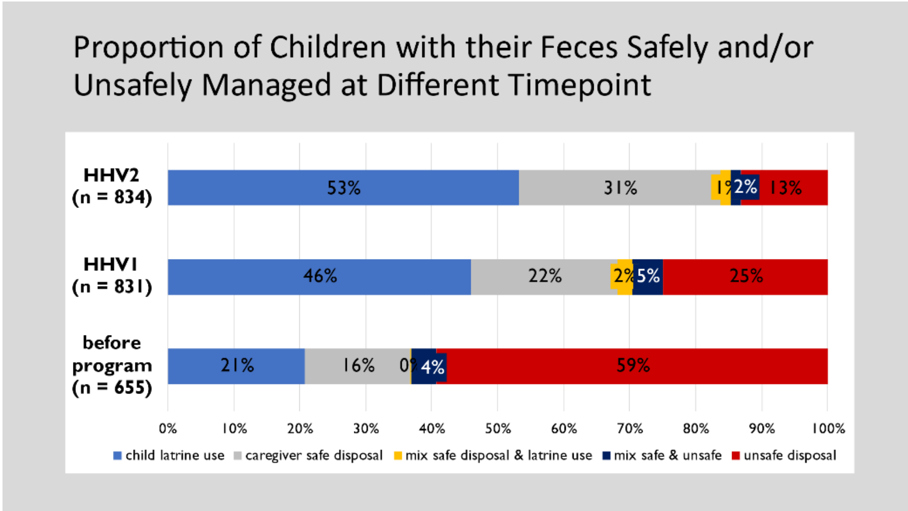
See full reports for detailed reporting on determinants of safe infant feces disposal (USAID, 2020b; USAID and Gram Vikas, 2021).

Figure 4. Testing enabling technologies for young child latrine use in Gram Vikas research, India.

Safe Disposal of Child Feces: Feasibility and Acceptability. In Bangladesh, icddr,b explored how to modify existing pit latrines to facilitate safe disposal of IYC feces (Huda et al., 2021). The small, multi-phase qualitative study began with four focus group discussions with mothers to explore barriers to child latrine use. These included the discomfort of squatting on a large pan, fear of darkness, and fear of a slippery floor. With barriers identified, 20 households with a child aged 3–7 years participated in testing six enabling technologies specifically designed to address the perceived barriers.

Several weeks later, researchers conducted in-depth interviews to assess acceptance, feasibility, and use. The study identified two options considered feasible and affordable to facilitate latrine use by children in this age group. One of the potential technologies, a ring to stabilize the child while squatting in the latrine was preferred by children and was considered by caregivers to be affordable and available. A second technology, a clear plastic roof, was also endorsed by caregivers and toddlers for reducing infant fear of dark latrines, increasing visibility and lighting, and keeping latrine floors drier. A wooden board with a smaller drophole for use over the typical pan reduced fears of falling and helped eliminate discomfort but was inconvenient to handle and clean.

In Odisha, India, Gram Vikas applied behavior surveys to assess caregivers' reported CFM practices for each child at three different time points: before the CFM program (655 children), in the week before household visit 1 (HHV1) (831 children), and in the week before household visit 2 (HHV2) (834 children). The study found that children's latrine use and caregivers' safe disposal steadily increased over time. Before the CFM program, only 21 percent of children used the latrine, but this increased to 46 percent by HHV1 and reached 53 percent by HHV2. Caregiver safe disposal also saw an increase over time: only 16 percent of children had their feces safely disposed of into a latrine before the program; this increased to 22 percent by HHV1 and reached 31 percent by HHV2. Consequently, these increases in safe CFM behaviors led to a large decline in the proportion of children who had their feces unsafely managed, from 59 percent before the program to only 13 percent by HHV2. A few caregivers practiced a mix of behaviors at any of the time points, be it a mix of safe behaviors or mix of safe and unsafe (USAID and Gram Vikas, 2021).



The steady increase in child latrine use and caregiver safe disposal differed by child age group, as expected, but did not differ by child sex. Children in the infant age groups saw a dramatic increase in caregiver safe disposal over time but no change in child latrine use, which was rarely practiced at that age. Toddlers between 1 and 3 years old can be viewed as the "transition" age group for CFM, where children become developmentally ready to transition from having their feces safely disposed to learning to use the latrine. This is evident in the survey results. The toddler age group increased in both caregiver safe disposal and child latrine use, with greater gains in safe disposal for younger toddlers and greater gains in child latrine use for older toddlers. Children >3 years old saw steady gains in child latrine use over time. As shown in other studies as well, despite other improved disposal practices by HHV2, caregiver safe disposal remained rarely practiced among children >3 years old. Instead, children in this age group who did not use the latrine had their feces unsafely disposed (USAID and Gram Vikas, 2021).

Neither of these studies assessed children's reduction in exposure to fecal contamination, nor did they evaluate the impact on child health outcomes.

Incorporating Safe CFM in National Community-Led Total Sanitation (CLTS) Strategies, Protocols, and Certification. Programs must be grounded in evidence, but also guided by national protocols and policies. The increased inclusion of safe disposal of infant feces in national strategies and protocols is notable and promises to provide the essential policy platform for increased budgeting and programming in this area. Currently, nine different CLTS/rural sanitation protocols or policies (between 2006 and 2019) include some criteria on child excreta management: Ethiopia (2006), Ghana open defecation free (ODF) certification criteria (2010), Timor-Leste (2012), Indonesia verification criteria (2013), Mali ODF certification protocol (2014), Cameroon National CLTS Strategy (2017), Zambia ODF Strategy (2018), Philippines Guidelines on Philippine Approach to Sustainable Sanitation (2019), and Cambodia National ODF verification Guidelines (2019). Another three national protocols/policies have a weaker mention: Sierra Leone ODF verification checklist (2012), Tanzania guidelines for ODF certification (2016), Nepal Total Sanitation Guideline (2017).

Safe Disposal of Child Feces: Takeaways. The two study results suggest that the combination of group and household strategies designed to focus on influential determinants of behavior (identified through formative research), together with increased access to "enabling technologies," may be effective at changing CFM and latrine training behaviors. Both studies also reinforce the need for context- and age cohort-specific technologies and behaviors that address the child's developmental stage including independence and mobility.

Given the relatively high prevalence and worldwide practice of unsafe IYC feces disposal, even in households with latrines and practicing fixed point defecation (documented earlier in this review), we suggest these combination of strategies offer promise as a key component of a combined strategy for improving the hygienic environments of IYC.

3.4 IMPROVED FLOORING

Research on Improved Flooring Interventions Since 2018. Evidence on the impact of improved flooring on child nutrition and health is limited to a single study in urban Mexico, where most of the households had cement floors (Cattaneo et al., 2009). Notably, open courtyards with bare loose soil are common in rural areas, where households are less likely to have cement floors. Human and animal density and flow of livestock in such contexts may influence the effectiveness of such improved floors on child health outcomes. The positive impact of cement floors on adult psycho-social well-being prompts further research questions on whether finished flooring is likely to improve WASH behaviors like cleaning the floor and keeping poultry and animals away, and more generally impact child health and growth in rural areas as well as the Mexican urban context.

The authors are not familiar with any new studies that conducted flooring interventions other than the study funded by WASHPaLS. The WASHPaLS study involved EarthEnable, a social enterprise that excavates dirt floors in rural households and replaces them with compacted earth that is sealed with a proprietary varnish which then hardens into a linoleum-like surface. The cross-sectional WASHPaLS flooring study involved 1) conducting in-depth interviews to explore the perceptions of improved and unimproved housing material and how installation of improved flooring alters behaviors; 2) assessing 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; and 3) measuring the amount of dust on improved and unimproved floors to produce a quantitative estimate of finished flooring's potential to reduce exposure to pathogens. The households with improved floors that were involved in the various study components had concrete or EarthEnable floors installed prior to selection for the study.

Improved Floors: Feasibility and Acceptability. Participants mentioned 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 harbored pests while others did not. They noted that some materials also shed dust, which they perceived to cause children to cough, in addition to soiling household items left in the open. Participants also reported that they considered some materials to be unsafe because they could catch fire. In addition to factors related directly to health and safety, a number of other factors influenced households in their choice of housing materials, including affordability, availability of natural resources, convenience, durability, cleanability, beauty, comfort, modernity, and respect (USAID and EarthEnable, 2021).

Installation of improved flooring is a one-time investment with very low maintenance requirements. The team's 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 and increase the amount of dirt and fecal matter removed from the house (USAID and EarthEnable, 2021).

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 for women, such as increased expectations to spend time and money to "look good and look modern" to match the handsome, modern flooring. 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 (USAID and EarthEnable, 2021).

Improved Floors: Reduction in Exposure. Controlling for type of object mouthed, mouthing rates were significantly lower when children were inside as opposed to outside. Considering all age groups combined, children (who performed the behavior) mouthed hands a median 31.3 times/hour, put objects in their mouths 8.7 times/hour, put food (excluding breastmilk) in their mouth 37.2 times/hour, and drank liquids 6.1 times/hour. Seventy-six (34%) children were observed putting soil or ash in their mouths, at a median rate of 0.7 times/hour, and 16 (7%) children were observed putting (human or animals) feces in their mouths, at a median rate of 0.2 times/hour. Nearly half (42%) of children <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 (USAID and EarthEnable, 2021).

One-quarter to one-third of children 12–47 months old were also observed mouthing soil during the six-hour observation period. Over 10 percent of children <11 months old and 2–8 percent of children 12–47 months old mouthed feces during the observation. 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/hour, and drank liquid 4.8 times/hour. Ten percent of pregnant women also mouthed soil; 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) (USAID and EarthEnable, 2021).

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 (USAID and EarthEnable, 2021). In Uganda, a limited amount of time spent inside and lower mouthing frequencies inside than outside suggest that improving indoor floors alone may not be sufficient to dramatically reduce children's exposure to fecal contamination and that improved flooring should be combined with interventions to reduce fecal contamination of the outside environment, such as animal feces management. More research is needed to confirm if this finding and recommendation is generalizable beyond Uganda, but it highlights the critical need to quantify the relative risk/protection of improving indoor flooring for improved IYC health outcomes.

Improved Floors: Impact on Environmental and/or Child Health Outcomes. 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 finished EarthEnable floors of 16.4 g/m^2. Substantially lower amounts of dust on improved 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 (USAID and EarthEnable, 2021). However, this reduction in exposure must be seen in the context of proportion of time spent indoors (on improved or unimproved flooring) and outdoors (on dirt).

Improved Floors: Takeaway. While children spend a majority 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 and could be combined with interventions such as animal feces management to support more hygienic environments for IYC. To increase uptake of improved flooring, implementing entities and market actors should frame affordable, non-concrete improved floors as aspirational endpoints rather than incremental stepping stones toward cement floors and discuss with customers/ beneficiaries gender-specific non-health benefits such as reduced workload and increased status and respect. Future research could also examine the impacts of improved flooring outdoors (as part of a veranda or patio) given that children spend so much time outside.

4.0 DISCUSSION AND RECOMMENDATIONS

The evidence presented in the sections above serves to further support the vital need to modify and expand the F-diagram, our operating paradigm guiding sources of fecal contamination and remediation, to include both animal and human sources of harmful pathogens as well as IYC-specific routes of exposure. We have enough evidence substantiating that "conventional WASH is necessary but not enough," that it is necessary to also improve the hygienic environment for better health, wealth, growth, and development of IYC. This document highlights there is no magic bullet, no one solution or intervention to effectively realize these improvements, rather that multi-modal and multi-sectoral strategies will be required.

We also know, as illustrated in this review, that generally "promoting behaviors" is not enough to improve the hygienic environment in which many IYC live. Behavior change activities that engage communication and outreach to promote improved practice cannot be an afterthought to a strategic approach to improving the hygienic environment; rather, we need to apply a behavioral lens as part of shaping strategies that go beyond promotion and effectively address the structural determinants and facilitators critical to improved practice as well.

4.1 DISCUSSION

The Role of "Enabling Products" in Improving Hygienic Environments for IYC. WASHPaLS grants and other research suggest that "enabling products" facilitate improved BabyWASH practices addressing infant-specific sources and pathways of contamination. With most of the behaviors outlined above, context-appropriate products are documented to facilitate recommended behaviors. Infant potties and san mats, chicken coops, playmats, and playpens each increase the likelihood of improved practice (see Figure 6).

While these products facilitate the improved practices, they are often *provided* to households without consideration of affordability, and it is not clear if resource poor households would be able to or would prioritize purchasing these products. This becomes a challenge for implementation and scale up of some "enabling product"-anchored interventions.

Several of the playpen studies provided sturdy, imported playpens to households (SHINE, Zambia TIPS), which the authors acknowledge was likely beyond the financial reach of participant families. Three other playpen studies incorporated "user-centered design" to engage users in the local design and production of playpens (Zambia TIPS, Sidama TIPS, WASHPaLS Amhara TIPS), assuming the strategy not only would reflect local context and preference but would also potentially lower costs to bring the products within range of target consumers).[3]

The WASHPaLS Amhara TIPS study assessed how much households valued the playpen by offering them the option to keep the playpen at the end of the study or receive USD17 in cash (the estimated cost of the playpens if they were eventually mass-produced at the national or local level and about half of the average monthly income of rural Ethiopian households). All households opted to forgo the cash and keep the playpens. This suggests the households highly valued the playpen, but it does not indicate that households would choose playpens if given the choice of spending money on food, school fees, or

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[3] Ethiopia is one of the poorest countries in the world, with an annual gross domestic product of USD 783, according to the World Bank (2019) (https://www.worldbank.org/en/country/ethiopia/overview). A typical Ethiopian farmer earns about USD 100/month from selling agricultural products and/or labor, to provide a relative comparison of value (K. Tegenfeldt, USAID Mission Addis Ababa, personal communication, April 14, 2020).

playpens, as the "endowment effect" could cause households to value the playpens more than they would have had they not already felt a sense of ownership over them (Morewedge et al., 2009).

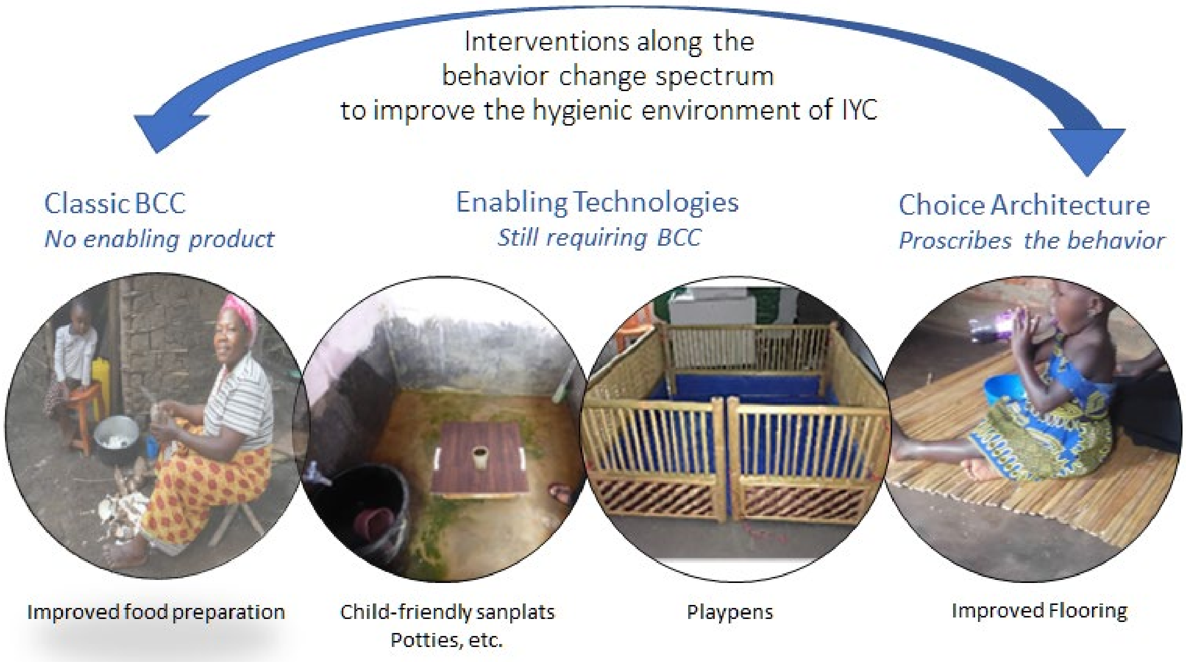

Figure 6. The role of technology and environment along a behavior change spectrum. *WASHPaLS hygienic environments research falls along a spectrum of behavior change interventions to potentially improve the hygienic environment for IYC. Some hygienic environment behaviors require primarily promotional BCC and interpersonal techniques, others are facilitated by an "enabling technology" (although still reliant on BCC), and still others at the far end of the spectrum require manipulation of the physical environment (a fixed change in the home or other setting). Also referred to as "choice architecture" (Thaler & Sunstein, 2008), this option literally directs users on the path to an improved practice without promotion—and perhaps without much conscious thought. Use of choice architecture encourages habit formation because it incorporates many of the key principles of habit formation: channeling a behavior to be repeated in a stable context, removing friction to carrying out the behavior, and eliminating choice or alternatives (Neal et al., 2015).*

The poultry night sheds tested by the icddr,b and The Water Trust studies were produced from locally available materials, but a lack of access to free natural resources required many households to purchase materials from the local market; this was identified as a barrier to building sheds and changing management practices. The icddr,b study provided a partial subsidy in one arm and no subsidy in the other arm. While more households constructed night sheds in the icddr,b subsidy arm than in the non-subsidy arm, the study suggests that households are willing and able to build sheds without a subsidy, but it may take longer than three months. The Water Trust study provided a loan with loan forgiveness if a certain percentage of households constructed night sheds. The study concluded that households were unlikely to build chicken runs and coops without some level of subsidization.

Table 2. Target behaviors for improved hygienic environments and their associated enabling technologies

Behavior	Enabling technology
Keep animals outside the child's sleeping room at night	• Night sheds for poultry • Corrals for ruminants
Prevent children from contacting soil and feces	• Playmats

Behavior	Enabling technology
	• Playpens • Improved flooring
Safely manage "productive" feces (to be used for fuel, building and/or fertilizer)	• Deep, covered pit • Composting away from domestic environment • Raised, covered storage (basket/bucket)
Safely collect and dispose of infant feces	• Child potties • "San mats" – mats specifically for defecating on • Animal feces scoops/hoes
Wash hands after touching animals or human or animal feces and before preparing food	• Handwashing stations near latrines, night sheds, food preparation areas

4.2 RECOMMENDATIONS

National and local government, funders, researchers, and implementers all have a critical role to play in supporting improved hygienic environments for IYC to grow and thrive. This begins with sector stakeholders considering the expanded F-diagram that includes IYC-specific sources and pathways for pathogens, such as direct ingestion of soil, ingestion of contaminated complementary food, and mouthing of contaminated hands. As we endeavor to establish best policy and practice, it is critical for donors, government and implementers to keep innovating, and measuring effectiveness, cost considerations, feasibility and appeal; while sharing both positive and negative learnings.

4.2.1 RECOMMENDATIONS FOR GOVERNMENTS AND FUNDERS

With the evidence base still emerging on how best to address the pathways in the expanded F-diagram, it is challenging to make definitive or specific policy recommendations for funders and governments. Government policy documents and program guidance will need updating to include this more comprehensive view of risk and exposure impacting health and growth, and the multi-modal/multi-sectoral approaches required to address the challenge require linkages across sector policies and initiatives.

USAID and other donor organizations are now suggesting that to improve IYC growth, WASH interventions must focus on applying context-based interventions that achieve area-wide scale (USAID 2020a). This shift is in part because there are no "silver bullet" interventions, and many of the benefits of WASH are dependent not only on improvements at the individual or household level but also on those taken up by neighbors and the surrounding community (Wolf et al., 2018; Jung et al., 2017; Larsen et al., 2017). Programmatic responses that minimize exposure to animal waste and human feces through the IYC-specific pathways (like the ones explored in this review) are also sometimes referred to as "BabyWASH" and "FarmWASH," respectively. BabyWASH and FarmWASH also are inherently multisectoral in nature, challenging many traditional funding and organizational structures. As noted above, neither playpens/mats nor improved flooring nor CFM alone are likely to address the IYC-expanded F-diagram pathways. This most likely means that in addition to being contextual, at area-wide scale, and multisectoral, interventions must be also multimodal—layering and sequencing a number of approaches. Governments and funders, therefore, need to support *transformational programming* that allows for flexibility to engage multiple sectors when needed, is agile to learning and innovations, and supports contextualization of interventions to these complex challenges in environmental health.

4.2.2 RECOMMENDATIONS FOR IMPLEMENTERS

Observational and experimental evidence that demonstrates the risks of unsafely managed human and animal feces continues to grow. Despite the interventions studied as part of WASHPaLS and other studies since 2018, there is still insufficient evidence to suggest a definitive intervention or interventions for implementers that will reduce IYC fecal oral transmission.

However, given the limited potential impact of any one intervention studied, it is most likely that a combination of interventions is the pathway to cleaner and safer environments for IYC. Implementers can partner with researchers to evaluate their interventions and increase the field's understanding how to prevent children's exposure to fecal contamination. While many implementers do not have the bandwidth or funding to implement area-wide WASH with multiple infant-specific initiatives, we suggest this transformational approach is part of any underlying "theory of change," and that IYC-focused "BabyWASH" programs co-locate and coordinate where more traditional WASH improvements are also targeted. To this area-wide WASH focus, it is recommended that implementers design, implement, and measure feasibility and uptake of interventions that build on their strengths and networks, and address the particular risk and context. Given the limited ability to assess intervention effectiveness without large-scale health outcome trials, the team recommends that implementers build on current evidence and conduct supplementary small-scale implementation trials of promising, multi-layered interventions to learn about their feasibility, affordability, and uptake. The team also suggests involving researchers or monitoring, evaluation, and learning specialists to help develop a limited set of indicators to be able to measure these variables.

The following are recommendations for incorporating behaviors covered in this review that likely reduce IYC-specific sources and pathways of fecal oral transmission. While there is currently insufficient evidence on the efficacy or effectiveness of these behaviors, they are still biologically plausible and logical. As described, it is mostly likely they are required to be regularly practiced in concert to limit fecal oral transmission and reduce disease. Below, we focus only on the behaviors covered in this review and refer readers to other resources which address a full complement of traditional and BabyWASH behaviors.[4]

1. Keep animals, especially poultry, outside the home.
    - Focus on nighttime cooping outside of the home and/or away from the sleeping area, as there is currently no evidence that suggests daytime confinement of poultry nor day or nighttime corralling of ruminants is associated with child health (Headey & Hirvonen, 2016).
2. Collect and dispose of child feces safely.
    - Based on age and context, different enabling technologies can facilitate safe collection of infant feces. Child potties can help caregivers safely collect the feces of very young children and dispose of them into a latrine. Dedicated scoops or hoes also serve to safely collect feces. Young children can also benefit from latrine modifications like a stabilization ring or a clear latrine roof to make using the adult latrine easier.
    - Dispose of child feces out of children's reach. This could be established by storing feces in a latrine or if not available or feasible in a deep pit to prevent flooding during the rainy season, and covering the pit to reduce access by children, flies, and other animals. Store feces until they decompose and are safe to handle (~1 year).

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[4] A set of Essential WASH Actions is found at https://www.fsnnetwork.org/resource/essential-wash-actions-training-and-reference-pack-supplement-essential-nutrition-actions. See page 49 of the GHP Handwashing Handbook for WASH Behavior Change resources: http://globalhandwashing.org/wp-content/uploads/2020/10/GHP_Handwashing-Handbook_FINAL.pdf

3. Caregivers wash hands with soap after contact with infant feces, animals and their feces as well as more traditional handwashing junctures.

4. Keep children and infants OFF of soil, especially when feeding and when animals are not segregated. This is facilitated by using a mat when eating, using a playpen during the day and/or installing a concrete or hard-packed earthen flooring coated in varnish inside the house to reduce indoor exposure to soil.

5. Encourage caregivers to prevent children from putting soil and feces in their mouth.
   - Provide low-contamination (e.g., plastic), easy-to-clean child stimulation toys, such as a plastic bottle with beans inside.

6. Keep the house and outdoor courtyard free of visible feces through regular monitoring and sweeping.
   - Whether householders choose to dispose, compost, or reuse as a fuel or building material, store/dispose of feces in a deep pit, to prevent flooding during the rainy season, and cover the pit to reduce access by children, flies, and other animals. If reusing the feces, store them until they are safe to handle
   - Discourage parents from assigning children to collecting feces (even older children will often serve as caretakers for the IYC, presenting risk of exposure).

4.2.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Interdisciplinary research bringing together transdisciplinary public health specialists, engineers, and behavioral scientists has the potential to advance hygienic environments for IYC by embarking on research to accomplish the following recommendations, which are prioritized by a combination of importance, feasibility and sequence in time and vary widely in scope and budget:

Near-term

1. Determine the pathways of viral, bacterial, and protozoan pathogen transmission for children <24 months old using location-specific contaminant concentrations and location-specific exposure factors, with a particular focus on pathogens associated with growth faltering, such as *Campylobacter, Cryptosporidium,* enteropathogenic *E. coli*, heat-stable enterotoxigenic *E. coli,* and *Shigella* (Nasrin et al., 2021).

2. Develop affordable, easy-to-clean, environmentally sustainable surfaces that are durable outdoors.

3. Work with implementers to design and conduct trials to evaluate the efficacy and sustainability of the following interventions on children's exposure to fecal contamination and pathogens and child health outcomes:
   - Carrying or otherwise elevating children to prevent their access to soil
   - Housing poultry outside the child's sleeping room at night
   - Implementing child potties and latrine modifications to make latrines child-friendly
   - Installing improved floors inside and/or outside the house
   - Collecting safe animal feces and composting or drying it for use as cooking fuel
   - Using mats while eating

4. Determine mechanisms to address the poultry husbandry poverty trap to motivate and incentivize households to use poultry night sheds and improve poultry feces management.

5. Determine the risk of handling and using fresh (cow) feces for fuel or building material and measure the reduction in contamination after allowing the feces to decompose over time or after they are processed in other ways.

6. Determine feasible, acceptable methods that rural households can use to dispose of or store animal feces for reuse such that heavy rains do not spread contamination around the domestic environment and children's access.

7. Develop methods to engage adults other than a child's primary caregiver in maintaining a hygienic domestic environment, for example:
   - Cleaning up animal feces
   - Monitoring children to reduce the frequency children mouth soil and feces

8. Test behavioral recommendations for caregivers to provide as toys objects that have surfaces that do not readily hold contamination, are easy-to-clean, and provide opportunities for child stimulation, in order to replace highly contaminated objects that children may otherwise play with, such as animal feces and shoes.

9. Assess the willingness and mechanisms for households to share relatively high-cost enabling technologies that are only used for a short period of a child's life, such as child potties, playpens, and "cleanable" toys.

10. Assess the feasibility of washing the hands of children <24 months at every recommended occasion for handwashing.

Long-term

11. Determine dose-response relationships for specific pathogens for children <24 months old in low-income countries.

12. Determine the association, if any, between the quantity of the fecal indicator bacteria, E. coli, and specific pathogens.

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