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Characterization and measurement of child exposure to zoonotic enteric pathogens in Esmeraldas Province, Ecuador

By

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Characterization and measurement of child exposure to zoonotic enteric pathogens in Esmeraldas Province, Ecuador

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April M. Ballard
B.A., Transylvania University, 2014
M.P.H., University of Kentucky, 2017

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An abstract of
A dissertation to the Faculty of the
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Abstract

Characterization and measurement of child exposure to zoonotic enteric pathogens in Esmeraldas Province, Ecuador

By April M. Ballard

Exposure to animal feces and associated enteric pathogens poses significant risks to child health. However, public health strategies to mitigate enteric infections among children largely focus on exposure to human feces, overlooking transmission pathways related to animal feces. The goal of this dissertation is to better understand if, why, how, and to what extent children are exposed to zoonotic enteric pathogens through 3 research aims.

Aim 1 characterized exposure among children aged 6-18 months old in northwestern coastal Ecuador. We conducted qualitative interviews with caregivers in households that owned and did not animals. We found that animals and their feces were ubiquitous – regardless of animal ownership – due to animal husbandry and feces management practices at the household- and community-level.

Aim 2 examined what types of animal fecal exposures have been assessed in human studies by auditing existing measurement. Exposure measures from included studies were classified in two ways. First, using a novel conceptual model, we categorized measures into 'Exposure Components' that were identified *a priori*: animal, environmental, and human behavioral. Second, using the exposure science conceptual framework, we determined where measures fell along the source-to-outcome continuum. Results revealed that existing measurement approaches are diverse and distal from exposure.

Aim 3 developed and validated a novel measure of child exposure to zoonotic enteric pathogens, and assessed exposure among children aged 6 months to 5 years old in northwestern coastal Ecuador. Using findings from aims 1 and 2, we generated a survey that we administered to mothers. We conducted principal component analysis to determine the optimal number of components and items to create an index to quantify exposure. The final measure consisted of seven interpretable components and 34 items. We found that child exposure to zoonotic enteric pathogens was ubiquitous. Only two children had no exposure.

Findings from this dissertation fill evidence gaps that improve the conception and measurement of child exposure to zoonotic enteric pathogens, which can enable and expand researchers' and practitioners' ability to assess exposure and develop and evaluate interventions.

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Chapter 1. Introduction

1.1. Motivation

Diarrheal disease and undernutrition are among the principal causes of morbidity and mortality in children under five years of age worldwide.[1-5] It is well established that exposure to enteric pathogens is a significant determinant of both diarrhea and malnutrition disease burdens.[6-13] Diarrhea is the fifth leading cause of death in children under five.[2,3,14] In 2019, there were approximately 580,000 diarrheal deaths,[14] which were caused by enteric pathogen infections such as cholera and rotavirus, among others.[11,12] Enteric infections also contributed to an unknown proportion of the 144 million stunting cases among infants and young children in 2019.[1,13,15] Diarrhea and enteric infections can impair gastrointestinal function and adversely impact child growth.[6,9,10,16-18] Persistent and recurrent infections during development can inhibit nutrient absorption and increase intestinal permeability (i.e., environmental enteric dysfunction),[16,17,19-21] leading to undernutrition, anemia, and cognitive deficits.[6,9,10,18] Enteric infections and acute sequalae during infancy are also associated with profound, poor health and economic outcomes in adulthood.[9,10,19,21]

Reducing fecal contamination and interrupting the principal fecal-oral transmission pathways are critical to prevent enteric infections, and thus resultant diarrhea and undernutrition.[11,12,22-24] Enteric pathogens are transmitted to humans when they ingest the feces of an infected host via the fecal-oral route. Transmission principally occurs when feces are ingested through contaminated fluids, food, fomites, fingers, fields, and flies, typically depicted by the F-diagram.[22-26] Historically, interventions that aim to reduce child diarrhea and stunting have attempted to interrupt transmission pathways by specifically reducing exposure to human feces.[23,27-32] Interventions typically include provision of water, sanitation, and hygiene (WASH) services, as inadequate and unsafe WASH is a well-documented cause of human fecal environmental contamination and transmission of enteric infections.[6,26,33-35] However, critical examination of primary enteric pathogen sources and transmission pathways has recently been

reinvigorated because evidence suggests that WASH provisions that focus on human feces may not address **all** key sources and transmission pathways.[28,29,35,36]

Recent systematic reviews and randomized control trials of WASH interventions designed to reduce child exposure to human feces have found varying effects on child health. Numerous reviews show that WASH interventions are associated with reductions in enteric infections and adverse health outcomes among children.[30,32,37-40] For example, a recent systematic review reported that improved drinking water with higher water quality on the premises reduced child diarrheal risk by 52% compared to unimproved water sources. Sanitation interventions and promotion of handwashing with soap reduced child diarrheal risk by 24% and 30%, respectively.[32] Other reviews have also found that WASH is protective against stunting[30,37] and infections such as trachoma[30,38] and soil-transmitted helminthiases.[30,39] In contrast, large-scale randomized control trials of WASH interventions have resulted in inconsistent effects on child diarrhea or linear growth. For example, two trials in India found that sanitation improvements had no effect on child diarrhea and growth,[41,42] while a combined water and sanitation trial in India improved child stunting but had no effect on diarrhea or other nutrition outcomes.[43] In multiple trials, enteric pathogen exposure and infection were largely unchanged even with high intervention fidelity and uptake.[28,35,36,41,42,44-46] Researchers conducted follow-up studies for two of the trials and found that WASH interventions did not significantly reduce fecal contamination for several transmission pathways.[47-49] Collectively, findings from these studies suggest that WASH interventions that target human feces are important for improving child health, but may overlook other significant sources of environmental fecal contamination and enteric pathogens, including those related to animal feces that are rarely assessed or targeted by interventions.[29,35,36]

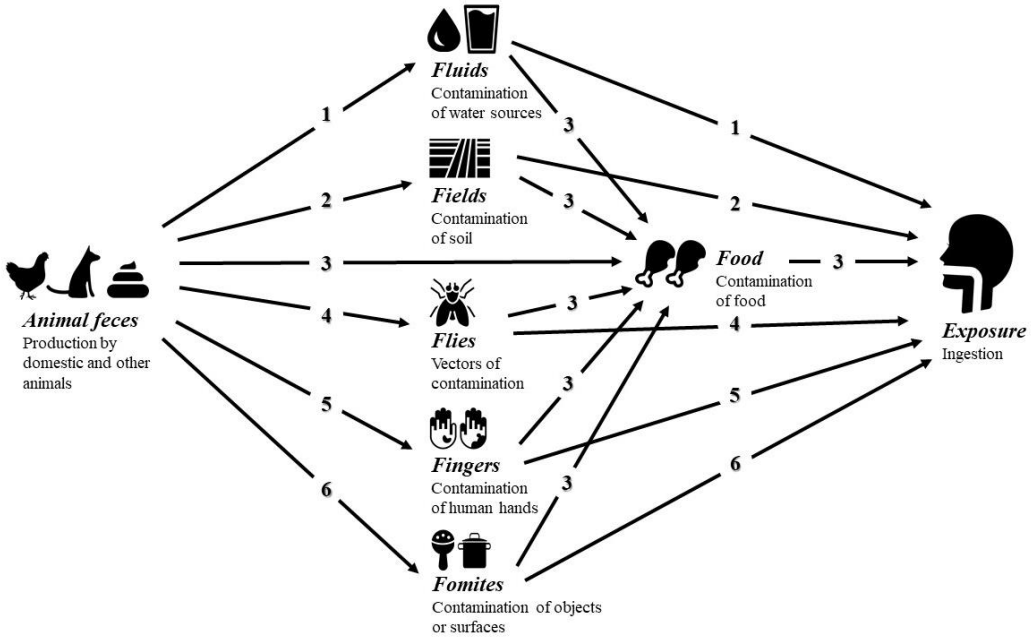
1.2. Exposure to zoonotic enteric pathogens

Exposure to animal feces is a threat to child health.[28,29,50-53] Animal feces production is four times that from humans, accounting for approximately 80% of the global fecal load.[54] Feces is largely produced at

the household-level,[54] and populations in low- and middle-income countries (LMICs) bear the greatest burden due to the ubiquity and proximity of animals in such settings.[51,53,55-57] Animal feces contains numerous pathogens that are capable of infecting humans, four of which (*Campylobacter* spp., *Cryptosporidium* spp., enteropathogenic *E. coli*, non-typhoidal *Salmonella* (NTS)) are responsible for approximately 30% of the 500,000 diarrheal deaths that occur annually in children under five years of age.[50] The true burden of disease associated with enteric pathogens of animal origin is currently unknown, but is likely substantial,[50,51] especially among children in LMICs where animals and their feces are abundant throughout domestic and public spaces.[53,55,56,58-60]

Existing research demonstrates that infants and young children, as well as others humans, are exposed to enteric pathogens in animal feces through pathways similar to those for human feces.[50,51] Figure 1.1 depicts a modified F-diagram based on current evidence and Penakalapati et al. (2017), which systematically reviewed literature to examine and categorize pathways of human exposure to zoonotic fecal pathogens using the traditional F-diagram.

Figure 1.1. Principal exposure pathways for fecal-oral transmission of zoonotic enteric pathogens to humans



Exposure to animal feces and related pathogens occurs through the following pathways:

1. *'Fluids' Pathway* – Contamination of human water can occur when animals are near or interact with water sources, and from animal feces runoff.[51] For example, a study in Bangladesh found that drinking water in compounds with animals had *E. coli* levels that were 0.40 $\log_{10}$ higher than those without animals.[61] In Indian villages in Odisha, animal fecal contamination was detected in 30% of public and private community water sources. Animal fecal material was detected 10 times more often than that from humans in ponds and 6 times more often in private tube wells.[62]

2. *'Fields' Pathway* – Fields or soil may be contaminated with animal feces from inadequate separation of animals from domestic and public spaces, as well as application of manure to fields.[51] A study in Bangladesh detected ruminant fecal contamination in 27% of household floor samples,[63] and another reported the presence of animals and animal feces in 94% and 89% of household compounds, respectively.[61] Research in rural Zimbabwe also found widespread fecal contamination in child households from chickens, including in backyards and kitchens.[64]

3. *'Food' Pathway* – Contamination of food can occur through the other F-diagram pathways (e.g., flies are in contact with food, food is prepared with contaminated water), as well as from direct contamination from animal feces.[51] Research suggests that in some contexts it is common for food preparation surfaces to be contaminated with animal feces,[51,65] and that the presence of animals is associated with higher levels of food contamination.[51,61] In Bangladesh, food in compounds with animals had higher levels of *E. coli* than those without animals. Food contamination was also higher in compounds where flies are present in food preparation areas.[61]

4. *'Flies' Pathway* – Flies can be vectors of fecal contamination or exposure due to presence and/or unsafe disposal of animal feces.[51] In Ethiopia, household proximity to animal pens and animal feces was associated with the presence of flies and increased risk of trachoma in children.[66] Other studies have also found associations between the presence of animals, flies and severity of

illness.[51] For example, a study in India showed that greater fly density was related to longer durations of diarrhea.[67]

5. *'Fingers' Pathway* – Direct contact with animal feces can contaminate human hands and result in ingestion of feces.[51] Child contact with animal feces in LMICs is well-documented.[51,68] In Peruvian households, researchers observed that in a 12-hour period children had contact with poultry feces 2.9 times and had 3.9 feces-to-mouth occurrences.[69] Studies in Bangladesh and Kenya found that child contact with and consumption of animal feces and contaminated soil was common.[28,68] Half of mothers in Bangladesh reported that their child touched or ate animal feces in the prior two weeks.[68] Thirty-nine percent of mothers in Kenya reported that their child consumed soil in the prior week.[28] Multiple studies also have found microbial fecal contamination on child hands from several types of animals.[70,71]

6. *'Fomites' Pathway* – Objects or surfaces may be directly or indirectly contaminated by animal feces.[51] For example, studies have found that presence and amount of animal feces is associated with high levels of toy contamination.[51,65,72] Research in Bangladesh revealed that mouthing contaminated objects accounted for 60% of the *E. coli* that a child ingested daily. The authors suggested that feces on objects was from soil contaminated with animal feces.[72] Additionally, in Peru, 75% of households had surfaces (e.g., floors, tables) contaminated with animal feces and 38% had contaminated child toys.[65]

Still, even though research on child exposure to animal feces is robust, critical evidence gaps limit researchers' and practitioners' ability to intervene on exposure and understand the magnitude of the issue. First, key human behaviors and conditions that influence exposure are unknown. Systematic reviews of literature on exposure to animal feces found that most research focuses on animal and environmental components of exposure.[50-52] Evidence on behavior is limited and often anecdotal. Given the central role of human behavior in exposure to animal feces, comprehensive research to understand the range of

exposure-related behaviors and practices is needed to identify significant behaviors for intervention. Second, community-level factors that may be root causes of exposure are not well documented or understood. For example, community norms related to animal husbandry and feces management practices can determine environmental fecal contamination and exposure. Existing research principally evaluates exposure based on individual and/or household features with little to no consideration to community characteristics' effect on exposure.[51,52] Future research to understand what sociocultural factors influence environmental fecal contamination and exposure and how factors vary across contexts will be critical to the development of culturally-appropriate, effective interventions. Third, there is neither consensus on nor a "gold standard" for measurement of exposure to animal feces.[50-52] As a result, animal feces exposure is measured using numerous proxies and methods (e.g., observation of human contact with animal feces,[73,74] microbiology assessment of environmental animal fecal contamination[75,76]). Current inconsistencies in measurement limit comparisons across studies and settings, and inhibit researchers' and practitioners' ability to understand the burden of disease associated with animal feces. In response to these research gaps, this dissertation seeks to improve and inform the conception and measurement of child exposure to zoonotic enteric pathogens through three research aims.

1.3. Dissertation research

This dissertation research is part of the 'Enteropatógenos, Crecimiento, Microbioma, y Diarrea' (ECoMiD) study, a longitudinal birth cohort study to examine environmental exposures impact on gut microbiome composition and development among children in northwestern coastal Ecuador.[77] The study aims to test the hypothesis that gut microbiota maturation and perturbations in the first two years of life mediate the effect of enteric infections on diarrhea, environmental enteric dysfunction, and growth. Although the cohort study extensively assesses environmental exposures through the measurement of fecal contamination across most principal transmission pathways, use of general fecal indicator bacteria (i.e., *Escherichia coli*) limits the study's ability to identify **specific sources** of contamination. This dissertation is part of a mixed methods supplemental study (referred to as the Animal Exposure [AnEx]

study) that expands the scope of ECoMiD by examining exposure to animal feces, an increasingly recognized source and transmission route of enteric pathogens. ECoMiD AnEx aims to characterize infant exposure to animals and animal-sourced contamination using environmental microbiology, qualitative, and survey-based methods. Examining specific sources of contamination and related transmission routes can help explain and contextualize ECoMiD environmental sampling and enteric infection results, and is critical to identify strategies for intervention.

This dissertation fulfills three research aims that are subsequently described, and carries out the qualitative and survey-based research for the ECoMiD AnEx study. Collectively, the aims investigate if, why, how, and to what extent children under two in the ECoMiD study area are exposed to animal feces. Findings from each aim will fill critical research gaps, and will also inform future data collection in the ECoMiD cohort to assess the relationship between animal feces exposure and infant gut characteristics.

Research aim 1 qualitatively examines if and how children are exposed to zoonotic enteric pathogens in communities along an urban-rural gradient in northwestern coastal Ecuador. Aim 1 addresses several key research gaps identified by past reviews and research priority papers.[28,29,51,52] For example, human behaviors and practices are vital to understanding and assessing exposure to animal feces, but existing research primarily focuses on animal and environmental exposure factors. The limited evidence on exposure-related behaviors is mostly anecdotal and is insufficient to collate a generalizable set of key behaviors across contexts. Additionally, there is a need for more research on sociocultural factors, such as animal husbandry and feces management practices, and their influence on transmission of pathogens between animals and children. By using a novel framework that conceptualizes exposure as a combination of animal, environmental, and human behavioral factors that are part of a broader sociocultural system, aim 1 addresses these gaps. The conceptual framework guides the investigation to identify behaviors and interactions that are central to child exposure, and capture factors that influence exposure at the community, household, and individual level. Data collected from multiple communities

along an urban-rural gradient using rigorous qualitative methods strengthen the validity and generalizability of findings.

Research aim 2 reviews and audits measurement of human exposure to animal feces to inform and improve exposure assessment. Because there are no “gold standard” or agreed upon measures of animal feces exposure, researchers use varied approaches, proxies, and methods. Varied and inconsistent measurement impedes understanding and quantification of the burden of disease attributable to human exposure to animal feces. Aim 2 serves to address current limitations related to measurement by auditing existing measures and identifying opportunities for improvement. Considered and consistent measurement will be critical to assessing the burden of disease related to animal feces and identifying high-risk areas for intervention.

Research aim 3 develops and validates a novel measure for child exposure to zoonotic enteric pathogens, and assesses exposure among children in northwestern coastal Ecuador. This aim addresses many of the same evidence gaps described for research aims 1 and 2, as well as others identified by aim 2. Briefly, we found that most existing measures of human exposure to animal feces are distal from exposure and do not account for the multiple causal conditions that constitute exposure (i.e., exposure’s multidimensionality). Findings underscore the need for a validated, standard measure that captures the many and most proximal constituents of exposure to expand researchers’ ability to assess and intervene on child exposure. Aim 3 improves upon existing measurement approaches by creating a composite index that captures the multidimensionality of exposure. The measure includes a set of items to assess child behaviors, which provides the opportunity to identify and understand key interactions associated with exposure, a significant evidence gap. The measure also assesses environmental conditions related to exposure to comprehensively capture exposure and facilitate identification of priority behaviors and environmental factors for intervention. Data collected from mothers across multiple communities elucidates the extent to which children are exposed to zoonotic enteric pathogens, how factors vary across communities, and how comparisons across contexts will be critical to the development of appropriate interventions.

1.4. Dissertation aims

Research aim 1

Child exposure to zoonotic enteric pathogens in northwestern coastal Ecuador: A qualitative study

Research aim 1 is to characterize if, how, and why children under two years are exposed to zoonotic enteric pathogens. This aim addresses the following questions:

i. What are animal, environmental, and behavioral factors and conditions related to child exposure to zoonotic enteric pathogens?
ii. How do factors and conditions vary across communities that differ in urbanicity and rurality?
iii. How do factors and conditions vary by household animal ownership?

Research aim 2

Measurement in the study of human exposure to animal feces: A systematic review and audit

Research aim 2 is to systematically review current types of animal fecal exposure assessed in human studies by auditing existing measurement. This aim serves to inform and improve approaches to the measurement of human exposure to animal feces by answering the following research questions:

i. What types of animal fecal exposures have been and have not been measured in human health studies in LMICs?
ii. What tools are used to evaluate human exposure to animal feces?
iii. What are the properties of available tools?

Research aim 3

The development and validation of a survey to measure fecal-oral child exposure to zoonotic enteropathogens: The FECEZ Enteropathogens index

Research aim 3 is to develop a novel multidimensional measure for child exposure to zoonotic enteric pathogens. The research questions for this aim were:

i. What are the constituents of and items needed to adequately measure child exposure to zoonotic enteric pathogens?
    a. What is the optimal number of factors or domains that fit the items?
    b. Are the scores based on items reliable and valid?

ii. What is the extent of exposure to zoonotic enteric pathogens among children under five in northwestern coastal Ecuador?
    a. Does exposure differ by animal ownership status and type of community?

1.5. Study setting

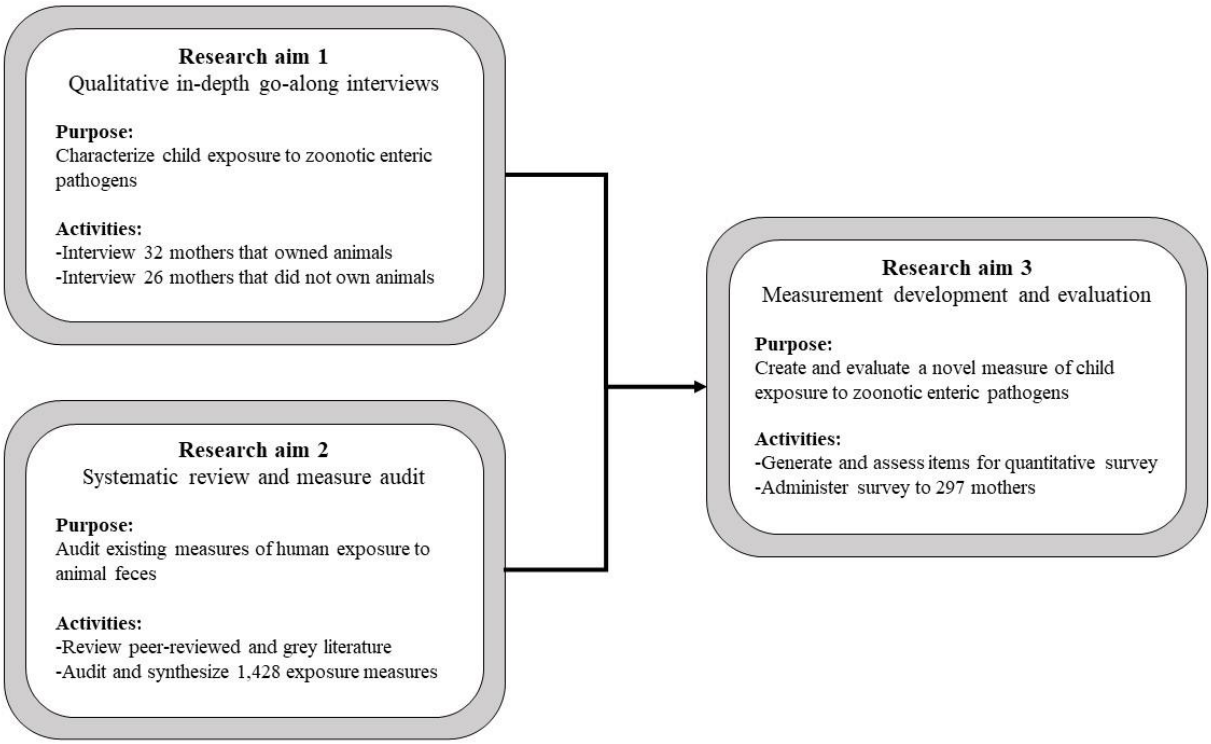
This dissertation characterizes child exposure to zoonotic enteric pathogens using qualitative, systematic review, and measurement development methods. All primary data collection occurred in communities in Esmeraldas Province in northwestern coastal Ecuador. The communities are included in an on-going longitudinal birth cohort study, ECoMiD, to examine environmental exposures impact on child gut microbiome composition and development. The birth cohort study enrolls mothers during pregnancy and follows the mother and their child until it reaches 24 months of age.[77]

Preliminary data from the ECoMiD cohort suggests that animals are prevalent in the region. For example, structured observation among ECoMiD cohort members revealed that animals were present in 58% of households, including dogs, chickens, cats, and ducks.[78] The study area also includes communities with differing urbanicity to intentionally capture variability in key public health features, such as water, sanitation, and animals. The urban study site, Esmeraldas city, has the greatest water and sanitation access, whereas the rural study sites predominantly consume untreated river water or rainwater.[77] Additionally, previous research has found that rural communities in the study area have greater animal species diversity (e.g., dogs, cats, chickens, pigs, cows, wild animals) compared to the more urban communities.[79] Further detail about the study area is provided in each aim's respective chapter.

1.6. Study design

Collectively, this dissertation takes a sequential mixed methods approach. Findings from research aims 1 and 2 were used to create and evaluate a novel measure to quantify child exposure to zoonotic enteric pathogens. An overview of the sequential approach is depicted in Figure 1.2 and detailed below.

Figure 1.2. Schematic of sequential mixed methods design of this dissertation



To characterize child exposure to zoonotic enteric pathogens (aim 1), we conducted go-along, in-depth interviews (IDIs) with infant caregivers whose child was between 6-18 months old from January through May 2021. Two types of participants were enrolled, mothers in households with at least 1 animal (n=32) and mothers in households with no animals (n=26). We sought variation in the types and numbers of animals owned to capture a representative sample and facilitate comparisons. Interviews asked about conditions and maternal and child behaviors that could lead to child exposure to zoonotic enteric pathogens with probes related to animals, environmental conditions, and behaviors.

To audit existing measures of human exposure to animal feces, we systematically searched peer-reviewed and gray literature databases in July 2022 (aim 2). Specific information about exposure measures was extracted for each included study, and measures were classified in two ways. First, using a novel conceptual model, we categorized measures into 'Exposure Components' that were identified *a priori*: animal, environmental, and human behavioral. Second, using the exposure science conceptual framework, we determined where measures fell along the source-to-outcome continuum.

Lastly, to create and evaluate a novel measure of child exposure to zoonotic enteric pathogens, we used a sequential mixed methods approach (aim 3). Findings from aims 1 and 2, in addition to data from IDIs with individuals who owned, cared for, or worked with animals (n=29, collected January-May 2021), were used to generate potential survey items. We finalized and evaluated the proposed items through expert review and cognitive interviews with individuals similar to our target population (n=20). Then, we collected cross-sectional data from August through September 2022 from 297 mothers with infants aged 6 months to 5 years old who were not enrolled in the cohort. Principal component analysis (PCA) was conducted to determine the optimal number of components for the measure. The PCA solution was used to create index scores, which were subsequently evaluated for reliability and validity.

1.7. References

1. World Health Organization. Levels and trends in child malnutrition: UNICEF. 2021.

2. Barredo L, Agyepong I, Liu G, Reddy S. Ensure healthy lives and promote well-being for all at all ages. *UN Chronicle*. 2015;51(4):9-10.

3. Hug L, Alexander M, You D, Alkema L, for Child UI-aG. National, regional, and global levels and trends in neonatal mortality between 1990 and 2017, with scenario-based projections to 2030: a systematic analysis. *The Lancet Global Health*. 2019;7(6):e710-e720.

4. Lozano R, Fullman N, Abate D, et al. Measuring progress from 1990 to 2017 and projecting attainment to 2030 of the health-related Sustainable Development Goals for 195 countries and territories: a systematic analysis for the Global Burden of Disease Study 2017. *The lancet*. 2018;392(10159):2091-2138.

5. Paulson KR, Kamath AM, Alam T, et al. Global, regional, and national progress towards Sustainable Development Goal 3.2 for neonatal and child health: all-cause and cause-specific mortality findings from the Global Burden of Disease Study 2019. *The Lancet*. 2021;398(10303):870-905.

6. Petri WA, Jr., Miller M, Binder HJ, Levine MM, Dillingham R, Guerrant RL. Enteric infections, diarrhea, and their impact on function and development. *J Clin Invest*. Apr 2008;118(4):1277-90. doi:10.1172/jci34005.

7. Siddiqui FJ, Belayneh G, Bhutta ZA. Nutrition and diarrheal disease and enteric pathogens. *Nutrition and infectious diseases*. Springer; 2021:219-241.

8. Eisenberg JN, Trostle J, Sorensen RJ, Shields KF. Toward a systems approach to enteric pathogen transmission: from individual independence to community interdependence. *Annu Rev Public Health*. Apr 2012;33:239-57. doi:10.1146/annurev-publhealth-031811-124530.

9. Guerrant RL, Oria RB, Moore SR, Oria MO, Lima AA. Malnutrition as an enteric infectious disease with long-term effects on child development. *Nutr Rev*. Sep 2008;66(9):487-505. doi:10.1111/j.1753-4887.2008.00082.x.

10. Guerrant RL, DeBoer MD, Moore SR, Scharf RJ, Lima AA. The impoverished gut--a triple burden of diarrhoea, stunting and chronic disease. *Nat Rev Gastroenterol Hepatol*. Apr 2013;10(4):220-9. doi:10.1038/nrgastro.2012.239.

11. Lanata CF, Fischer-Walker CL, Olascoaga AC, et al. Global Causes of Diarrheal Disease Mortality in Children <5 Years of Age: A Systematic Review. *PLOS ONE*. 2013;8(9):e72788. doi:10.1371/journal.pone.0072788

12. Wang H, Naghavi M, Allen C, et al. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet*. 388(10053):1459-1544. doi:10.1016/S0140-6736(16)31012-1.

13. Verma P, Prasad JB. Stunting, wasting and underweight as indicators of under-nutrition in under five children from developing Countries: A systematic review. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*. 2021;15(5):102243.

14. Vos T, Lim SS, Abbafati C, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*. 2020;396(10258):1204-1222.

15. Smith LC, Haddad L. Reducing child undernutrition: past drivers and priorities for the post-MDG era. *World Development*. 2015;68:180-204.

16. Blanton LV, Barratt MJ, Charbonneau MR, Ahmed T, Gordon JI. Childhood undernutrition, the gut microbiota, and microbiota-directed therapeutics. *Science*. 2016;352(6293):1533-1533.

17. Lunn P. The impact of infection and nutrition on gut function and growth in childhood. *Proc Nutr Soc*. 2000;59:147.

18. Lunn PG. Growth retardation and stunting of children in developing countries. *British Journal of Nutrition*. 2002;88(2):109-110. doi:10.1079/BJN2002652

19. Kane AV, Dinh DM, Ward HD. Childhood malnutrition and the intestinal microbiome. *Pediatric research*. 2015;77(1):256-262.

20. Gordon JI, Dewey KG, Mills DA, Medzhitov RM. The human gut microbiota and undernutrition. *Science translational medicine*. 2012;4(137):137ps12-137ps12.

21. Keusch GT, Denno DM, Black RE, et al. Environmental Enteric Dysfunction: Pathogenesis, Diagnosis, and Clinical Consequences. *Clin Infect Dis*. 2014:S207-12. vol. Suppl 4.

22. Eisenberg JN, Trostle J, Sorensen RJ, Shields KF. Toward a systems approach to enteric pathogen transmission: from individual independence to community interdependence. *Annual review of public health*. 2012;33:239.

23. Eisenberg JNS, Scott JC, Porco T. Integrating Disease Control Strategies: Balancing Water Sanitation and Hygiene Interventions to Reduce Diarrheal Disease Burden. *American Journal of Public Health*. 2007;97(5):846-852. doi:10.2105/ajph.2006.086207.

24. E.G. Wagner JNL. Excreta disposal for rural areas and small communities. *Monogr Ser World Health Organ*. 1958;39.

25. Pickering AJ, Ercumen A, Arnold BF, et al. Fecal Indicator Bacteria along Multiple Environmental Transmission Pathways (Water, Hands, Food, Soil, Flies) and Subsequent Child Diarrhea in Rural Bangladesh. *Environmental Science & Technology*. 2018/07/17 2018;52(14):7928-7936. doi:10.1021/acs.est.8b00928.

26. Kosek MN, Ahmed T, Bhutta Z, et al. Causal pathways from enteropathogens to environmental enteropathy: findings from the MAL-ED birth cohort study. *EBioMedicine*. 2017;18:109-117.

27. Prüss-Ustün A, Wolf J, Bartram J, et al. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. *International journal of hygiene and environmental health*. 2019;222(5):765-777.

28. Pickering AJ, Null C, Winch PJ, et al. The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health*. 2019;7(8):e1139-e1146.

29. Prendergast AJ, Gharpure R, Mor S, et al. Putting the "A" into WaSH: a call for integrated management of water, animals, sanitation, and hygiene. *The Lancet Planetary Health*. 2019;3(8):e336-e337.

30. Freeman MC, Garn JV, Sclar GD, et al. The impact of sanitation on infectious disease and nutritional status: a systematic review and meta-analysis. *International journal of hygiene and environmental health*. 2017;220(6):928-949.

31. Sclar GD, Penakalapati G, Amato HK, et al. Assessing the impact of sanitation on indicators of fecal exposure along principal transmission pathways: a systematic review. *International journal of hygiene and environmental health*. 2016;219(8):709-723.

32. Wolf J, Hubbard S, Brauer M, et al. Effectiveness of interventions to improve drinking water, sanitation, and handwashing with soap on risk of diarrhoeal disease in children in low-income and middle-income settings: a systematic review and meta-analysis. *The Lancet*. 2022;400(10345):48-59.

33. Goddard FG, Pickering AJ, Ercumen A, Brown J, Chang HH, Clasen T. Faecal contamination of the environment and child health: a systematic review and individual participant data meta-analysis. *The Lancet Planetary Health*. 2020;4(9):e405-e415.

34. Gizaw Z, Yalew AW, Bitew BD, Lee J, Bisesi M. Fecal indicator bacteria along multiple environmental exposure pathways (water, food, and soil) and intestinal parasites among children in the rural northwest Ethiopia. *BMC gastroenterology*. 2022;22(1):84-84. doi:10.1186/s12876-022-02174-4.

35. Cumming O, Cairncross S. Can water, sanitation and hygiene help eliminate stunting? Current evidence and policy implications. *Maternal & child nutrition*. 2016;12:91-105.

36. Cumming O, Arnold BF, Ban R, et al. The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. *BMC medicine*. 2019;17(1):1-9.

37. Dangour AD, Watson L, Cumming O, et al. Interventions to improve water quality and supply, sanitation and hygiene practices, and their effects on the nutritional status of children. *Cochrane Database Syst Rev*. Aug 1 2013;(8):Cd009382. doi:10.1002/14651858.CD009382.pub2.

38. Stocks ME, Ogden S, Haddad D, Addiss DG, McGuire C, Freeman MC. Effect of water, sanitation, and hygiene on the prevention of trachoma: a systematic review and meta-analysis. *PLoS Med*. Feb 2014;11(2):e1001605. doi:10.1371/journal.pmed.1001605.

39. Strunz EC, Addiss DG, Stocks ME, Ogden S, Utzinger J, Freeman MC. Water, Sanitation, Hygiene, and Soil-Transmitted Helminth Infection: A Systematic Review and Meta-Analysis. *PLOS Medicine*. 2014;11(3):e1001620. doi:10.1371/journal.pmed.1001620.

40. Freeman MC, Stocks ME, Cumming O, et al. Systematic review: Hygiene and health: systematic review of handwashing practices worldwide and update of health effects. *Tropical Medicine & International Health*. 2014;19(8):906-916. doi:10.1111/tmi.12339.

41. Clasen T, Boisson S, Routray P, et al. Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial. *The Lancet Global Health*. 2014;2(11):e645-e653.

42. Patil SR, Arnold BF, Salvatore AL, et al. The effect of India's total sanitation campaign on defecation behaviors and child health in rural Madhya Pradesh: a cluster randomized controlled trial. *PLoS medicine*. 2014;11(8):e1001709.

43. Reese H, Routray P, Torondel B, et al. Assessing longer-term effectiveness of a combined household-level piped water and sanitation intervention on child diarrhoea, acute respiratory infection, soil-transmitted helminth infection and nutritional status: a matched cohort study in rural Odisha, India. *International Journal of Epidemiology*. 2019;48(6):1757-1767. doi:10.1093/ije/dyz157

44. Maleta KM, Manary MJ. WASH alone cannot prevent childhood linear growth faltering. *The Lancet Global Health*. 2019;7(1):e16-e17.

45. Null C, Stewart CP, Pickering AJ, et al. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. *The Lancet Global Health*. 2018;6(3):e316-e329.

46. Stewart CP, Kariger P, Fernald L, et al. Effects of water quality, sanitation, handwashing, and nutritional interventions on child development in rural Kenya (WASH Benefits Kenya): a cluster-randomised controlled trial. *The lancet child & adolescent health*. 2018;2(4):269-280.

47. Ercumen A, Pickering AJ, Kwong LH, et al. Do sanitation improvements reduce fecal contamination of water, hands, food, soil, and flies? Evidence from a cluster-randomized controlled trial in rural Bangladesh. *Environmental science & technology*. 2018;52(21):12089-12097.

48. Ercumen A, Mertens A, Arnold BF, et al. Effects of single and combined water, sanitation and handwashing interventions on fecal contamination in the domestic environment: a cluster-randomized controlled trial in rural Bangladesh. *Environmental science & technology*. 2018;52(21):12078-12088.

49. Pickering AJ, Swarthout J, Mureithi M, et al. Can individual and integrated water, sanitation, and handwashing interventions reduce fecal contamination in the household environment? Evidence from the WASH Benefits cluster-randomized trial in rural Kenya. *BioRxiv*. 2019:731992.

50. Delahoy MJ, Wodnik B, McAliley L, et al. Pathogens transmitted in animal feces in low- and middle-income countries. *International Journal of Hygiene and Environmental Health*. 2018/05/01/ 2018;221(4):661-676. doi:https://doi.org/10.1016/j.ijheh.2018.03.005.

51. Penakalapati G, Swarthout J, Delahoy MJ, et al. Exposure to Animal Feces and Human Health: A Systematic Review and Proposed Research Priorities. *Environmental science & technology*. 2017;51(20):11537-11552. doi:10.1021/acs.est.7b02811.

52. Zambrano LD, Levy K, Menezes NP, Freeman MC. Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. Jun 2014;108(6):313-325. doi:10.1093/trstmh/tru056.

53. Gharpure R, Mor SM, Viney M, et al. A One Health Approach to Child Stunting: Evidence and Research Agenda. *The American Journal of Tropical Medicine and Hygiene*. 2021;104(5):1620.

54. Berendes DM, Yang PJ, Lai A, Hu D, Brown J. Estimation of global recoverable human and animal faecal biomass. *Nature Sustainability*. 2018;1(11):679-685.

55. Barnes AN, Mumma J, Cumming O. Role, ownership and presence of domestic animals in peri-urban households of Kisumu, Kenya. *Zoonoses and public health*. 2018/02// 2018;65(1):202-214. doi:10.1111/zph.12429.

56. Barnes AN, Anderson JD, Mumma J, Mahmud ZH, Cumming O. The association between domestic animal presence and ownership and household drinking water contamination among peri-urban communities of Kisumu, Kenya. *PloS one*. 2018;13(6):e0197587-e0197587. doi:10.1371/journal.pone.0197587.

57. Lowenstein C, Waters WF, Roess A, Leibler JH, Graham JP. Animal Husbandry Practices and Perceptions of Zoonotic Infectious Disease Risks Among Livestock Keepers in a Rural Parish of Quito, Ecuador. *The American journal of tropical medicine and hygiene*. 2016;95(6):1450-1458. doi:10.4269/ajtmh.16-0485.

58. Ngure FM, Humphrey JH, Mbuya MNN, et al. Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *The American journal of tropical medicine and hygiene*. 2013;89(4):709-716. doi:10.4269/ajtmh.12-0568.

59. Ngure F, Gelli A, Becquey E, et al. Exposure to livestock feces and water quality, sanitation, and hygiene (wash) conditions among caregivers and young children: Formative research in rural Burkina Faso. *The American journal of tropical medicine and hygiene*. 2019;100(4):998.

60. Thomas ED. Hens, housing, and hygiene: formative research in rural Bangladesh for interventions to separate young children from poultry and poultry feces. Johns Hopkins University; 2021.

61. Ercumen A, Pickering AJ, Kwong LH, et al. Animal feces contribute to domestic fecal contamination: evidence from E. coli measured in water, hands, food, flies, and soil in Bangladesh. *Environmental science & technology*. 2017;51(15):8725-8734.

62. Schriewer A, Odagiri M, Wuertz S, et al. Human and animal fecal contamination of community water sources, stored drinking water and hands in rural India measured with validated microbial source tracking assays. *American Journal of Tropical Medicine and Hygiene*. 2015;93(3):509-516.

63. Harris AR, Pickering AJ, Harris M, et al. Ruminants Contribute Fecal Contamination to the Urban Household Environment in Dhaka, Bangladesh. *Environ Sci Technol*. May 3 2016;50(9):4642-9. doi:10.1021/acs.est.5b06282.

64. Ngure FM, Humphrey JH, Mbuya MNN, et al. Formative Research on Hygiene Behaviors and Geophagy among Infants and Young Children and Implications of Exposure to Fecal Bacteria. *American Journal of Tropical Medicine and Hygiene*. October 2013;89(4):709-716.

65. Schiaffino F, Rengifo Trigoso D, Colston JM, et al. Associations among Household Animal Ownership, Infrastructure, and Hygiene Characteristics with Source Attribution of Household Fecal Contamination in Peri-Urban Communities of Iquitos, Peru. *Am J Trop Med Hyg*. Jan 2021;104(1):372-381. doi:10.4269/ajtmh.20-0810.

66. Cumberland P, Hailu G, Todd J. Active trachoma in children aged three to nine years in rural communities in Ethiopia: prevalence, indicators and risk factors. *Trans R Soc Trop Med Hyg*. Feb 2005;99(2):120-7. doi:10.1016/j.trstmh.2004.03.011.

67. Collinet-Adler S, Babji S, Sarkar R, et al. Environmental indicators of diarrhea in Vellore, India. *American Journal of Tropical Medicine and Hygiene*. 2011;85(6):175.

68. Ngure FM, Reid BM, Humphrey JH, Mbuya MN, Pelto G, Stoltzfus RJ. Water, sanitation, and hygiene (WASH), environmental enteropathy, nutrition, and early child development: making the links. *Ann N Y Acad Sci*. Jan 2014;1308:118-28. doi:10.1111/nyas.12330.

69. Marquis GS, Ventura G, Gilman RH, Porras E, Miranda E, et al. Fecal Contamination of Shanty Town Toddlers in Households with Non-Corralled Poultry, Lima Peru. *American Journal of Public Health*. February 1990;80(2):146-9.

70. Boehm AB, Wang D, Ercumen A, et al. Occurrence of Host-Associated Fecal Markers on Child Hands, Household Soil, and Drinking Water in Rural Bangladeshi Households. *Environmental Science & Technology Letters*. 2016;doi:10.1021/acs.estlett.6b00382.

71. Harris AR, Pickering AJ, Harris M, et al. Ruminants Contribute Fecal Contamination to the Urban Household Environment in Dhaka, Bangladesh. *Environmental Science & Technology*. May 2016;50(9):4642.

72. Kwong LH, Ercumen A, Pickering AJ, et al. Ingestion of fecal Bacteria along multiple pathways by young children in rural Bangladesh participating in a Cluster-Randomized trial of water, sanitation, and hygiene interventions (WASH benefits). *Environmental science & technology*. 2020;54(21):13828-13838.

73. Medgyesi DN, Brogan JM, Sewell DK, Creve-Coeur JP, Kwong LH, Baker KK. Where Children Play: Young child exposure to environmental hazards during play in public areas in a transitioning internally displaced persons community in Haiti. *International Journal of Environmental Research and Public Health*. 2018;15(8):1646.

74. Rivero M, Passucci J, Lucchesi P, et al. Epidemiology of hemolytic uremic syndrome in two regions of Buenos Aires Province. *Medicina*. 2013;73(2):127-135.

75. Fuhrmeister ER, Ercumen A, Pickering AJ, et al. Effect of sanitation improvements on pathogens and microbial source tracking markers in the rural Bangladeshi household environment. *Environmental science & technology*. 2020;54(7):4316-4326.

76. Holcomb DA, Knee J, Sumner T, et al. Human fecal contamination of water, soil, and surfaces in households sharing poor-quality sanitation facilities in Maputo, Mozambique. *International journal of hygiene and environmental health*. 2020;226:113496.

77. Lee GO, Eisenberg JNS, Uruchima J, et al. Gut microbiome, enteric infections and child growth across a rural–urban gradient: protocol for the ECoMiD prospective cohort study. *BMJ Open*. 2021;11(10):e046241. doi:10.1136/bmjopen-2020-046241.

78. Sosa-Moreno A, Lee GO, Van Engen A, et al. Characterizing Behaviors Associated with Enteric Pathogen Exposure among Infants in Rural Ecuador through Structured Observations. *The American Journal of Tropical Medicine and Hygiene*. 2022;106(6):1747.

79. Sánchez X, Smith SM, Montero L, et al. Locals get travelers' diarrhea too: risk factors for diarrheal illness and pathogenic E. coli infection across an urban-rural gradient in Ecuador. *Trop Med Int Health*. 2019;24(2):205-2019.

Chapter 2. Research Aim 1: Child exposure to zoonotic enteric pathogens in northwestern coastal Ecuador: A qualitative study[1]

2.1. Abstract

Exposure to animal feces and associated enteric pathogens poses significant risks to child health. However, public health strategies to mitigate enteric infections among children largely aim to reduce exposure to human feces, overlooking transmission pathways related to animal feces. The aim of this study is to examine if and how children are exposed to zoonotic enteric pathogens across communities in northwestern coastal Ecuador. We conducted qualitative interviews with mothers of children aged 6-18 months that owned (*n*=32) and did not own (*n*=26) animals in urban and rural communities. Using thematic analysis, we identified community, household and child behavioral factors that influence exposure. We compared child exposure by household animal ownership and across communities. Our findings revealed myriad opportunities for young children to be exposed to zoonotic enteric pathogens in many locations and from multiple animal sources, regardless of household animal ownership. Animal feces removal and disposal practices used by mothers, such as rinsing feces into ditches and throwing feces into surrounding areas, may increase environmental contamination outside their home and in their community. Unsafe animal feces management practices (AFM) were similar to child feces practices reported in other studies, suggesting that animal feces may contaminant the environment along a similar management pathway – which includes practices related to defecation, feces removal and disposal, defecation location cleaning, and handwashing. Identification and incorporation of safe AFM practices, similar to those developed for child feces management, could mitigate child zoonotic exposures by reducing animal feces contamination in domestic and public spaces. Building upon safe child feces management programs could enable the development of an integrated approach to address enteric pathogen exposure pathways related to animal and child feces.

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2.2. Introduction

Exposure to enteric pathogens during childhood is associated with substantial disease burden. Enteric and diarrheal infections are the fifth leading cause of death in children under age five.[1-5] Persistent exposure to enteric pathogens and recurrent infections during childhood can result in serious, lifelong ailments, such as environmental enteric dysfunction, increased risk of other infections, deficits in child growth, and reduced cognitive development.[6-12] Children in low- and middle-income countries (LMICs) bear the greatest burden of enteric disease due to pervasive fecal contamination in domestic environments and inequities in water, sanitation, and hygiene (WASH).[13,14]

Transmission of enteric pathogens can occur through several fecal-oral pathways, typically referred to as the F-diagram.[15] Humans may become infected through fluids, food, fomites, fingers, fields, and flies that are contaminated with feces from humans and animals.[15-19] The provision of WASH services is a well-established public health strategy to prevent transmission of enteric pathogens, typically by targeting exposure to human feces.[14,16,20,21] Transmission of enteric pathogens from animal feces has been overlooked in most WASH programming to date.[19,22-24] Animals produce approximately four times as much feces as humans,[25] and many pathogens capable of infecting humans are in animal feces.[26]

Community, household, and child practices and behaviors play a key role in exposure to zoonotic enteric pathogens. Animal husbandry and feces management practices, which are determined by various household and community factors, can increase contamination of the environment.[18,27] Children are then exposed through their interactions with contamination in the environment or on objects.[18] Current evidence on behaviors is minimal and insufficient for determining a generalizable set of behaviors that influence zoonotic exposures.[18,19,24,28] Community- and household-level factors related to animal husbandry and feces management[18,23,24,27,29] may be root causes of exposure. For example, animal feces may be abundant throughout the domestic environment, regardless of household-level animal ownership, because letting animals roam freely to forage for food is a norm that is perceived as beneficial to animals and reduces the financial burden of animal feed.[27,30-33] Identifying the upstream causes of environmental

fecal contamination and exposure will be critical to the development of effective mitigation strategies that can be integrated into WASH programming. Furthermore, understanding the range of behaviors and conditions that influence exposure can offer a more holistic approach to characterize child exposure to animal feces, which is often done through measuring the presence of animals and animal feces in the household environment.[18,28]

This study addresses key evidence gaps by using qualitative methods to explore the interrelated community, household, and child behavioral factors that influence exposure. We sought to understand if and how children are exposed to zoonotic enteric pathogens across communities in northwestern coastal Ecuador. We compare opportunities for exposure across urban and rural communities, highlighting the ubiquity of animals across settings which is applicable to other LMICs. We also explore how household animal ownership influences exposure opportunities, which can provide important insights for potential mitigation strategies.

2.3. Methods

Study design and setting

We conducted qualitative research in northwestern coastal Ecuador to understand if, why, how, and to what extent children are exposed to zoonotic enteric pathogens. To examine how community- and household-level factors may influence exposure, we interviewed mothers in urban and rural communities that owned and did not own animals. Mothers were selected from four sites included in an on-going longitudinal birth cohort study in Ecuador. This study, known as ECoMid,[34] follows mother-child dyads from pregnancy through 24 months to examine how environmental exposures impact child gut microbiome composition and development.

The present study was conducted in (1) Esmeraldas (hereafter referred to as the urban community); (2) Borbón (the semi-rural community); (3) rural villages near Borbón accessible by road (the rural road communities); and (4) rural villages near Borbón only accessible by boat (the rural river communities).

The study area is primarily populated by Afro-Ecuadorians, with an increasing number of people of mixed race (mestizos) in rural road communities and a small number of Chachis, an indigenous group, in rural river communities. Esmeraldas is the urban hub of the study area and capital of Esmeraldas Province, with a population of over 160,000,[35] It is densely populated and has the most access to WASH, roads, and medical infrastructure. Borbón is a town in Esmeraldas Province located at the confluence of the Cayapas, Santiago, and Onzole Rivers (population: 7,700).[35] Borbón has underdeveloped infrastructure for its size, and basic WASH infrastructure of variable quality. Along the three rivers, there are about 125 small villages, each with 50-500 residents. Some of the villages have access to a road connected to Borbón, while others are more remote with access only via river. These rural road and river communities have minimal infrastructure and predominantly use untreated river water, though some leverage rainwater. Few rural communities have access to wells or piped water, though several rural road villages have been connected to water systems recently,[36,37]

Sample and participant selection

To examine how household-level factors may influence exposure, we enrolled two types of participants from the ongoing ECoMid birth cohort: (1) mothers in households that owned at least one animal (n=32) and (2) mothers in households that did not own animals (n=26). Our original study design called for 30 interviews with animal-owning mothers and 30 with non-animal-owning mothers, which was based on recommendations to conduct at least 16-24 IDIs and to have a larger sample when studying complex topics.[38,39] Mothers were eligible if their child in the cohort was between 6-18 months old. This age range was selected because children become mobile and active during this time, making them particularly susceptible to environmental exposures. We used purposive quota sampling to ensure an equal number of mothers who did and did not have animals in each of the four study sites, if possible. To capture variability, we included mothers that owned different types and numbers of animals. Local study staff facilitated recruitment in each community by calling cohort mothers who had a child between 6-18 months old to query their animal ownership status and interest in participating. The final sample consisted

of 58 mother-child dyads from four study sites along an urban-rural gradient. Mothers were 28 years old on average (range: 19-47 years). Children were 10 to 18 months old and approximately half (52%, *n*=30) were female. Our final sample did not include children between 6-10 months old because few children that age were enrolled in the cohort at the time of recruitment. The type of water, sanitation, and animals owned varied along the urban-rural gradient. Sixty-six percent of households used water from an improved source for children and 81% had improved sanitation facilities. Over half of mothers who did not own animals (58%, *n*=15) at the time of the interview had previously owned animals. Additional demographic information for the total sample and by study site are presented in Table 2.1.

Table 2.1. Mother-child characteristics and demographics

	Total n (%)	**Urban n (%)**	**Semi-rural n (%)**	**Rural road n (%)**	**Rural river n (%)**
	58 (100)	18 (31)	20 (34)	14 (24)	6 (10)
Maternal characteristics					
Age (years; mean [range])	28 (19-47)	28 (19-47)	26 (19-35)	29 (21-39)	30 (22-38)
Education (mean [range])	11 (0-17)	11 (5-16)	10 (0-16)	12 (7-17)	7 (0-12)
Child characteristics					
Age (months; mean [range])	14 (10-18)	14 (10-18)	14 (11-18)	14 (10-17)	16 (13-18)
Sex – male	28 (48)	11 (61)	8 (40)	4 (29)	5 (83)
Household characteristics					
Household size (mean [range])	5 (3-13)	5 (3-8)	5 (3-13)	5 (3-10)	5 (3-8)
# of children (mean [range])	3 (1-6)	3 (1-6)	2 (1-4)	3 (2-6)	2 (1-4)
Floor material					
Cement	32 (55)	14 (78)	7 (35)	8 (57)	3 (50)
Ceramic tile	13 (22)	3 (17)	5 (25)	4 (29)	1 (17)
Wooden boards	13 (22)	1 (6)	8 (40)	2 (14)	2 (33)
Wall material					
Cement or cement blocks	52 (90)	14 (78)	14 (70)	12 (86)	4 (67)
Wooden boards	10 (17)	1 (6)	6 (30)	2 (14)	2 (33)
Bricks	3 (5)	3 (17)	0 (0)	0 (0)	0 (0)
Roof material					
Metal	52 (90)	15 (83)	20 (100)	11 (79)	6 (100)
Cement	3 (5)	3 (17)	0 (0)	0 (0)	0 (0)
Paving stone	3 (5)	0 (0)	0 (0)	3 (21)	0 (0)
Sanitation type					
Indoor toilet connected to sewer systems, septic tank, or pit latrine	47 (81)[a]	14 (78)	16 (80)	13 (93)	4 (67)
Indoor toilet that discharges to another location	1 (2)	0 (0)	0 (0)	0 (0)	1 (17)
Pit latrine without a slab	2 (3)	0 (0)	1 (5)	0 (0)	1 (17)
Water source for child					
Piped	23 (40)[b]	7 (39)	10 (53)	6 (43)	0 (0)
Bottled/Purchased	14 (24)	1 (6)	5 (26)	8 (57)	0 (0)
Tube well	1 (2)	0 (0)	1 (5)	0 (0)	0 (0)

Public Tap	11 (19)	10 (56)	1 (5)	0 (0)	0 (0)
River	2 (3)	0 (0)	2 (10)	0 (0)	0 (0)
Rain	6 (10)	0 (0)	0 (0)	0 (0)	6 (100)
Animal ownership					
Dogs	21 (36)	9 (50)	6 (30)	4 (29)	2 (33)
Cats	21 (36)	5 (28)	6 (30)	6 (43)	4 (67)
Creole chickens	6 (10)	1 (6)	3 (15)	2 (14)	1 (17)
Production chickens	3 (5)	0 (0)	3 (15)	0 (0)	1 (17)
Pigs	4 (7)	0 (0)	2 (10)	1 (7)	1 (17)

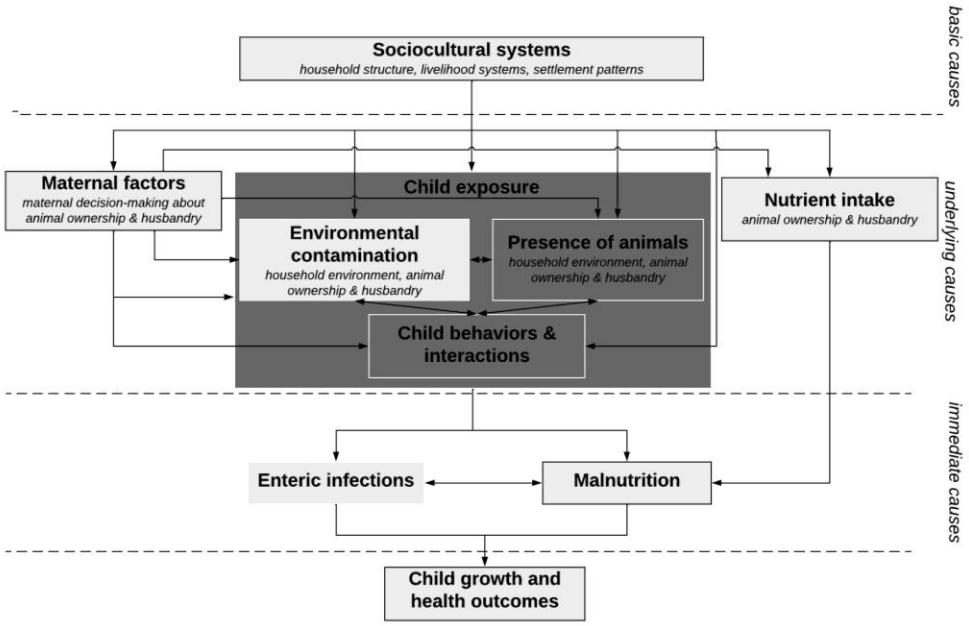
a. Data was missing for 8 participants (4 urban, 3 semi-rural, 1, rural road)
b. Data was missing for 1 semi-rural participant

Data collection

Author BCA, who is from Esmeraldas and has conducted qualitative research locally for more than 10 years, conducted go-along, semi-structured in-depth interviews (IDIs) in Spanish from January to May 2021. We chose to do go along IDIs because they enable simultaneous observation and interviewing as the interviewer and participant inhabit and engage with the spaces they are discussing,[40,41] which is ideal for our study objective.

Leveraging UNICEF's 1990 conceptual framework of undernutrition[42] and the agriculture-nutrition pathways framework,[43,44] we created the Maternal and Animal-related Determinants of Child Health (MADCH) framework (Figure 2.1) to visually depict how child health is influenced by zoonotic enteric infections and to inform the creation of the IDI guide. We used UNICEF's 1990 framework because our study was conducted before the 2020 framework was released and because the 2020 framework does not include the household environment, which is central to our study.[45] Our adapted MADCH framework encompasses basic (i.e., sociocultural systems), underlying (i.e., maternal factors, animal-related child exposure, and nutrient intake), and immediate (i.e., enteric infections and malnutrition) causes and pathways of child growth outcomes from the two existing frameworks and extends the underlying theories to examine child exposure to pathogens of animal origin. In this study, we explored sociocultural, maternal, and animal exposure factors that may impact child health. Nutrient uptake was not explored as it was outside the scope of the study. Analyses to investigate maternal decision-making related to child exposure were conducted separately and will be presented in a separate manuscript.

Figure 2.1. Maternal and animal-related determinants of child health conceptual framework, presenting causes and pathways of child exposure to zoonotic enteric pathogens and child-nutrition linkages*



*This conceptual framework was modified from UNICEF's undernutrition framework (shown in light grey) and the agriculture-nutrition pathways framework (indicated by solid outlined boxes). Light gray boxes with solid outlines are from both frameworks. Dark grey indicates our novel contributions.

IDI questions and probes focused on the basic and underlying causes of child exposure, specifically capturing details about sociocultural systems, mothers, animals, environmental contamination, and child behaviors. To understand the myriad ways that young children may be exposed to zoonotic enteric pathogens, mothers were asked about a typical day for them and their child. Probes queried details about animals, environmental conditions, behaviors, and seasonality because interviews were conducted during the rainy season. The interview concluded with questions about reasons for and benefits of animal ownership and intra-household decision-making related to animals and the child. Basic demographics, household characteristics, and the type and number of animals (if any) owned by participants were collected via a short survey.

Systematic debriefing sessions were held between author AMB and BCA throughout data collection using a standard set of questions[46] to ascertain emerging themes in the data and enhance our approach in real time. IDIs were conducted in a comfortable and private space where the mother and interviewee could be

at least six feet apart due to COVID-19 safety concerns. Interviews lasted 27 minutes on average (range: 15-50 minutes) and were audio recorded, transcribed, de-identified, and translated from Spanish to English verbatim. When mothers refused to be audio recorded (*n*=17), the interviewer took detailed notes and created a transcript using the interview guide immediately following the interview. Mothers received an assortment of food items (e.g., rice, beans) as compensation for their time.

Data analysis

To identify key themes in the data, we conducted thematic analysis using MaxQDA 2020 software (VERBI Software, Berlin, Germany). A codebook with deductive and inductive codes was developed iteratively throughout the analysis process using the MADCH framework, transcript readings, and debriefing notes. To standardize our coding approach and ensure reliability, we double-coded two sets of five transcripts, cross-checking coding strategies and interpretation of data by each coder after each set. Subsequently, transcripts were double-coded 10 at a time, after which coding agreement was checked to address inter-rater reliability issues. Then, the two coders systematically debriefed,[46] resolved coding differences, and wrote memos on key themes. We did not inter-rater agreement statistics to assess inter-rater reliability because coding was part of the process to discover themes so agreement was not always the goal,[47] and differences in coding style result in artificial low agreement.[47,48]

We assessed code and meaning saturation throughout the coding process[38,39,49] by tracking the number of additional codes and code definition changes there were after each round of coding (i.e., every 10 transcripts). Code saturation was considered to be achieved when 90% of meaningful codes were identified and developed, which occurred after coding five transcripts in this study. Meaning saturation was considered to be met when 90% of core codes had fully developed characteristics, which occurred after coding 10 transcripts. After coding, segments from transcripts for each code and intersections of prominent codes were queried and memos were written. Queries, memoing, and debriefing were performed iteratively to explore, describe, compare, conceptualize, and explain key themes. Mothers' animal ownership status at the time of the interview was used to conduct comparative analyses.

Ethics

All participants provided written consent prior to data collection and received a copy of the consent form. Participants' right to skip questions and end interviews at any time was emphasized by the interviewer. Institutional Review Boards at Emory University (IRB # 00101202) and Universidad San Francisco de Quito (IRB # 2018-022M and 021-011M) approved all study procedures.

2.4. Results

We identified animal, environmental, and behavioral features of child exposure to zoonotic enteric pathogens, which we conceptualized as the basis of exposure for this study (i.e., the dark grey box in the MADCH framework – Figure 2.1). Figure 2.2 illustrates the myriad factors that were reported by mothers inside (#1) and outside (#2) of the home that present opportunities for child exposure. Other common locations where children were reported to spend time (i.e., playgrounds [#3], bingo gatherings [#4], and relatives' and neighbors' homes [#5], are also depicted. Factors included the presence of various types of animals and animal feces, family members contact with animals and animal feces, child behaviors and interactions, seasonal and animal ownership variability, and those related to the sociocultural context. In-depth descriptions of exposure-related factors are provided in the following section, first for the household then for other locations. We compare factors and conditions among households that do and do not own animals and across communities throughout.

Inside the household

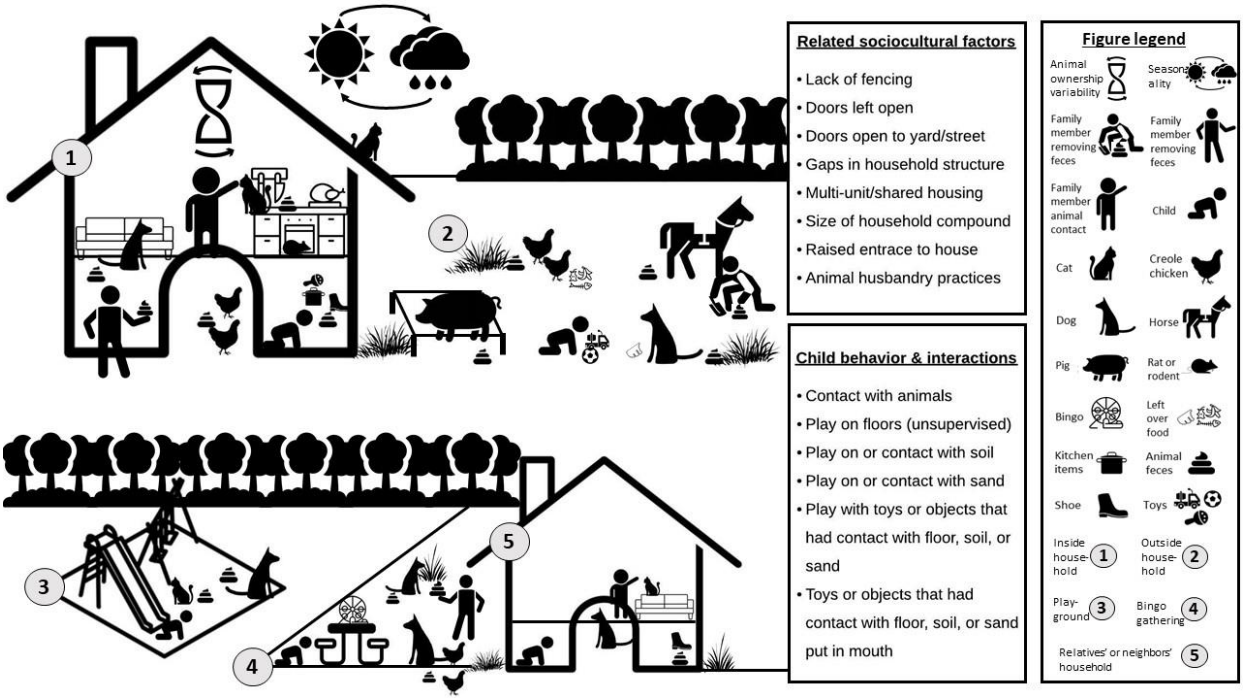
Children spent the majority of the day inside their household, resulting in expansive discussion of indoor factors and conditions that may lead to exposure to zoonotic enteric pathogens. Below, we expand upon indoor animal, environmental, and behavioral factors and condition of child exposure.

Presence of animals inside the household

The daily presence of animals inside was extensive, and even common among those who did not own animals, though to a lesser extent. Nearly all mothers who owned animals (94%, *n*=30), and

approximately 40% (*n*=10) of those who did not, reported the presence of animals inside their house on a typical day. Most reported that one type of animal entered regularly (i.e., cats, dogs, or creole chickens). Overwhelmingly, mothers who owned animals reported that those **they own** entered (88%, *n*=28), though six reported that stray animals or those owned by neighbors and family members entered. No mothers from animal-owning households in the rural river communities reported that their animals entered the household.

Figure 2.2. Factors and conditions of child exposure to zoonotic enteric pathogens



Cats were the most common animal reported inside, regardless of ownership status. Those that were stray or owned by others entered households that did and did not own animals. It was difficult to keep cats out because they entered through household gaps or openings, especially at night. Cats spent time on living room furniture near where children played, under or on dining room tables where food was consumed, and/or in kitchens where food was prepared.

> *"The cats come in and out of the house. They get under the bed, under the dining table. The dog also enters and leaves, but spends more time outside…The cats spend time in the kitchen, on the floor, under the dog…"*

-age 32, Rural road communities, owns one dog and two cats

Most mothers who owned dogs (76.2%, *n*=16) reported that their dog(s) entered their household on a typical day. Dogs owned by others or that were stray were not indoors frequently; three mothers from urban animal-owning households and one who did not own animals reported the presence of a dog inside. Dogs spent substantial time roaming freely throughout communities, though they briefly and frequently came inside to be fed, escape bad weather conditions, spend time with the family, and/or because household doors were left open.

"…He sleeps outside here in this part of the hall. Today, because of the heavy rain, I opened the door and made him come inside. I had him come in because he was pretty wet."

-age 29, urban community, owns one dog

Six mothers (two that owned animals and four that did not) reported that free-range creole chickens entered their households. Creole chickens were not "allowed" inside, but mothers were unable to prevent them from entering due to household doors being open, creole chickens roaming free throughout the day, lack of fencing which allowed chickens to move from yard to yard, and chickens' constant scavenging for food. A few mothers reported that the raised entrance to their house prevented chickens from entering. For example, one mother's house was raised up on stilts so the entrance to their house was approximately three meters off the ground. No chickens entered non-animal-owning households in urban or remote river communities.

Presence and management of environmental contamination inside the household

Indoor animal fecal contamination was reported by 40% of mothers, largely a result of animal feces being brought inside via shoes or toys. Indoor contamination from shoes or toys was reported in every community and there were no differences by animal ownership status. Household members inadvertently stepped in or put toys in animal feces from dogs, cats, creole chickens, or an undisclosed source outside the household.

> *"…Animal feces are brought inside, especially from dogs, on children's shoes…it can happen suddenly. There are remains [of animal feces outside] and children while playing at night do not see well and step in it and bring it in on their shoes."*
>
> -age 26, rural road communities, owns two dogs and one cat

Contamination from animals defecating inside occurred in all communities and in households that did and did not own animals, though it was more common in animal-owning households. Mothers reported that their animals defecated indoors (i.e., dogs, cats, and creole chickens). A few reported stray or others' animals defecating inside: two mothers reported that someone else's creole chickens defecated inside in the mornings on a typical day, one reported that their landlord's dog defecated in a shared hallway, and another found neighbors' cat's feces approximately once a month. In the urban, rural road, and rural river communities, rat feces were observed in kitchens by the interviewer, though mothers did not discuss this. Indoor animal fecal contamination was typically cleaned with water and products such as bleach or diesel. Descriptions of fecal removal and disposal strategies and related factors are presented in Table 2.2.

Table 2.2. Maternal animal feces removal and disposal strategies for inside and outside households and factors that influence strategies used

Type of feces	Removal and/or disposal strategies	Factors influencing strategies	Example
Cat	-Via trash service -Throw into nearby vacant lot -Throw into surrounding vegetation -Bury with soil or sand	-Feces is dried out when found -When/if trash pickup will occur -Location found -Proximity to vacant lot -Pandemic conditions/awareness	"We throw the cat feces away to the trash…but now let's say, we are constantly cleaning. We throw chlorine because of what we are going through [with the pandemic]." -age 35, semi-rural community, owns one dog and one cat
Dog	-Via trash service -Wash away with water -Throw into septic tank -Throw into nearby vacant lot -Throw into surrounding vegetation or area, including rivers -Bury with soil or sand	-Feces is dried out when found -When/if trash pickup will occur -Location found (e.g., inside home, outside where child plays, etc.) -Proximity to vacant lot or river - Other animal owners' strategies	"We throw it out because the owner doesn't pick it up… [we throw it] out in front where there's that piece of land. That's where we throw it." -age 32, urban community, non-animal owner
Creole chicken	-Throw into nearby vacant lot -Throw into surrounding vegetation, including rivers -Bury with soil or sand -Wash away with water, including letting rain wash it away -Collect and store for fertilizer	-Feces is dried out when found -When/if trash pickup will occur -Location found -Proximity to vacant lot or river - Other animal owners' strategies -Feces contained to cage or spread throughout environment -Have use for fertilizer	"There is chicken feces in the yard. The yard is open and the neighbor has some chickens and they go in the yard. I don't know how much feces because [the neighbor] knows how to clean. She scoops it up or covers it with dirt and I don't always realize it." -age 25, rural road communities, non-animal owner
Production chicken	-Via trash service -Throw into surrounding vegetation	-When/if trash pickup will occur -Feces contained to cage or spread throughout environment	"…The feces dry out and mix with the sawdust and it is not eliminated daily. The feces are thrown away with the sawdust and we change it one or two times a week." -age 31, semi-rural community, owns three production chickens
Pig	-Wash away with water	-Feces contained to pigsty -Proximity to river	"We throw [the pig feces] away by the 'plan,' a ravine." -age 35, rural river communities, owns four creole chickens, four dogs, four cats, and two pigs
Horse	-None	-Other animal owners' strategies	"From horses, it occurs usually two or three times daily. When they poop, the owner comes down and cleans it. When they are in a hurry, they leave it." -age 36, rural river communities, owns one cat

Mothers, siblings, other family members, and guests who interacted with children under 18 months had frequent contact with animals and/or animal feces, regardless of household ownership status. Contact varied in intensity with animals such as dogs, cats, creole chickens, and pigs. Mothers had contact with and helped care for their animals and those owned by family members. Older siblings commonly had contact with dogs and cats. Mothers found it more appropriate for older children to interact with and care for animals. Contact with animal feces indoors was not discussed explicitly or prominently. Some mothers used a general "we" when reporting indoor fecal removal practices (e.g., "We throw it out."), suggesting that multiple household members have contact with animal feces and may contribute to contamination of children's interpersonal environment.

Child behaviors and interactions inside the household

Most children had contact with dogs (e.g., petting, grabbing, and playing with them), who, as previously described, spent substantial amounts of time outdoors. Dogs that children had contact with were theirs, their relatives', or their neighbors'. Some children had contact with cats (e.g., grabbing, touching, and carrying them), though most did not because mothers stated that cats "carry disease" and "cause asthma." One mother encouraged her child's contact with cats and dogs.

> *"For my way of thinking, [animal contact] is so nothing will make her sick so that her body is adjusted to cats and dogs…so I tell her to touch them for her body's reaction…"*
>
> -age 25, urban community, non-animal owner

No mother reported direct contact with animal feces, though children often played in indoor environments contaminated with animal feces.

All but seven children were free to crawl or walk, often unsupervised, throughout the house in the mornings and afternoons while mothers performed chores and cared for their other children, and during this time children played with toys and objects that could be or could become contaminated with animal feces and related pathogens. Creole chickens and dogs were more active and reportedly entered households during mornings and afternoons, indicating that children may be in the same space as animals

and their feces unsupervised. Children threw objects on the ground repeatedly and continued playing with them, increasing the likelihood that objects and child hands may become contaminated. For example, eight mothers reported children playing on the bare floor with kitchen objects (e.g., pots, pans, spoons, glasses) that were later used for cooking and food or water consumption.

> *"He goes to the kitchen and takes out everything he finds, the pots, lids, glasses."*
>
> -age 25, rural road communities, non-animal owner

Other objects that children played with may be contaminated with animal feces and related pathogens due to being high-touch objects or their functional purpose (e.g., a tool for cleaning). Most children played with high-touch objects, such as television remotes and cell phones. Six mothers reported that their child played with or touched outdoor shoes. Lastly, a few children played with objects used to clean (e.g., brooms).

> *"The shoes [are her favorite toy]. And…what she likes to grab the most is also here in the kitchen…she grabs the pans or she starts to play with the trays…She grabs the broom, she puts it down and starts sweeping."*
>
> -age 19, semi-rural community, non-animal owner

We found no differences in behaviors and interactions across community type or by animal ownership status.

Outside the household

Animals and their feces were more pervasive outside in the household compound compared to inside the home. However, children typically spent less time outside and the frequency and proportion of outdoor playing among children increased along the urban-rural gradient. Few in the urban community played outside and if they did, it was infrequent or rare. The majority of children in the semi-rural and rural road communities played outdoors regularly, and virtually all children in the rural river communities played outdoors habitually.

Presence of animals outside the household

All but one mother reported having animals outside near their household on a typical day. Most observed more than one type, including dogs, cats, creole chickens, horses, and pigs. Dogs and cats were most common, though there was more diversity in the types of animals present in non-urban communities.

Cats were in 72% of animal-owning (*n*=23) and 46% of non-animal-owning (*n*=12) mother's yards or on their roof at night, though some reported their presence during the day. Some mothers made cats leave immediately, some gave them food regardless of ownership, and others did nothing unless the cat entered the house.

> *"Sometimes, when I have some rice left, I feed [the neighbor's cats, dogs, and chickens] with it…I just give them food, that's it. Then they leave."*
>
> -age 26, rural river communities, non-animal owner

All but five mothers reported that dogs they owned, that were stray, and/or that were owned by others were outside in the household compound or entryway in the mornings and afternoons. Dog owners let their dogs roam free during the day to urinate, defecate, and/or scavenge for food. Mothers that owned and did not own animals tried to get the dogs to leave, while others let them remain. Some inadvertently or intentionally encouraged the presence of dogs by putting leftover food outside to feed the dogs to avoid food waste, regardless of ownership status. One mother who did not own animals got dogs to leave sometimes and fed them other times.

> *"[The dogs] pass by, sometimes they stop to look to see if someone will feed them…Sometimes I drive them away. I make them run away. Other times when I have food, I put it out for them…they come by three times in a day."*
>
> -age 25, urban community, non-animal owner

Forty-one percent of mothers who owned animals (*n*=13) and 23% who did not own animals (*n*=23), largely from non-urban communities, reported that either creole or production chickens were present outside on a typical day. Creole chickens were more common than production chickens; only three

mothers discussed production chickens, which they personally owned. Production chickens remained in mothers' yards, caged and unable to roam free. Creole chickens roamed free in the mornings to forage for food and were placed in enclosures near households in the afternoon or at night for protection, a common practice in the region. Creole chickens roamed from compound to compound because yards were not enclosed. Most mothers did not deter the presence of creole chickens, though encouraged their presence by putting leftover food outside, similar to dogs. Variability in creole and production chicken ownership arose as an important factor that may impact how and the extent to which children are exposed over time. There were fluctuations in the number of chickens owned over short periods of time, which was unique compared to other types of animals and was often related to human consumption. Seasonality also influenced household chicken husbandry because of flooding due to the wet tropical climate of the study area.

Pigs and horses were outside four households in non-urban communities. Pigs were contained within pigsties outside of two households that owned them, one in the rural river communities and one in the semi-rural community. Horses were outside two non-animal-owning households in the rural river communities regularly, walking by with their owners as they traveled to and from agricultural fields to help farmers or by themselves without their owners. No other information was provided about horses.

Presence and management of environmental contamination outside the household

Outdoor fecal contamination was common. All but nine mothers reported the presence of animal feces outside near their household on a typical day. Contamination was most often a result of animals—including cats, dogs, production and creole chickens, pigs, and horses—defecating outside near households and not from shoes and objects. Most mothers found 2-4 piles of dog feces in the mornings and afternoons multiple times a week to every day, regardless of animal ownership. Mothers who owned dogs reported that they defecated far from their house, but dogs that were stray or owned by others defecated outside near their house. Cat feces was present outside households sometimes, regardless of cat ownership. Mothers reported not seeing cat feces because it was buried in dirt or sand. However, some

households had piles of sand outside their house where others' cats and dogs would defecate. Other types of animal feces were found less often. Every creole chicken-owner and some of those who did not own creole chickens found creole chicken feces in their yard and/or near the entrance of their house. The few mothers who owned production chickens and pigs reported the presence of their feces outside their household. Production chickens and pigs were contained within pens or pigsties, which also contained their feces.

Differences in the type of animal feces present outside of households were seen across communities. Cat and dog feces were common in the urban community. Cat, dog, and production and creole chicken feces were common in the semi-rural community. Cat, dog, creole chicken, pig, and horse feces were common in the rural road and river communities.

Mothers used multiple and varying approaches to remove or dispose of animal feces depending on the type of animal and other factors (e.g., feces are dried out when found, when or if trash services will occur). In the urban community, mothers disposed of animal feces in the trash, which was picked up by a garbage service that was more consistent and available. In the semi-rural community, mothers removed feces from their yard and put them in the trash to be removed by a garbage service, or by throwing it into vacant lots or the surrounding vegetation. In rural communities, animal feces were thrown into vacant lots or the surrounding vegetation (rural road communities) or in the river (rural river communities). More details about the removal and disposal of feces by animal species are provided in Table 2.2.

Similar to inside households, mothers and older siblings were reported to have contact with animals outside the household. Some had more intense contact, such as cleaning or bathing pigs that they owned. However, many mothers had less intense interactions with animals. For example, some walked and cared for family member's dogs and others fed dogs, cats, and creole chickens leftover food.

Family member contact with animal feces outside households was discussed more explicitly and commonly compared to inside households. Contact with dog feces was most common followed by creole

chicken feces. Mothers, fathers, and grandparents disposed of feces outside households in hopes of allowing children to play in feces-free environments, though efforts were not always successful.

> *"[I find dog feces] sometimes, not every day…The day before yesterday the [child's toy] motorcycle even got dirty [with animal feces] …I had to wash it there with water and a piece of broom that was not used."*
>
> -age 39, rural road communities, non-animal owner

Child behaviors and interactions outside the household

Few children had direct contact with animals outside, and most mothers reported limiting their child's contact. Among those who did have contact, behaviors with dogs and cats were the same as those described with animals inside. Contact with dogs, owned by them or others, was most common. A few children had direct contact with cats. No child had contact with chickens or pigs outdoors. It was more common for children in rural road and river communities to have contact with dogs and cats.

Many children played outside in the area surrounding their household where mothers also reported the presence of animals and their feces. No mother discussed children having contact with animal feces outside, although many reported child behaviors may lead to exposure if animals and/or fecal contamination are present (see examples below). Children played with toys, sticks, soil/mud, and rocks in spaces where animals and/or their feces were present, increasing the risk of object and hand contamination. Some mothers reported toys becoming contaminated with animal feces when their child played with them outside.

> *"…She wants to take everything she sees from the ground, stones, pieces of branches, sticks. But I don't let her because afterwards she puts her dirty hands in her mouth…"*
>
> -age 26, rural road communities, owns two dogs and one cat

Unlike inside households, it was uncommon for a child to be unsupervised while playing outside. When mothers were not supervising their child, another person (i.e., sibling, neighbor, relative) was. It was commonly described that someone held children's hands while outside, likely related to their walking

proficiency and developmental stage. We found no differences in outdoor child behaviors and interactions by animal ownership status.

Other non-household locations

Most children spent time in locations other than their household where animals and animal feces were present, including relatives' and neighbors' households, mother's businesses, community parks, and outdoor bingo gatherings. Mothers would often leave their children with others and/or were not always present at others locations.

Presence of animals in other non-household locations

Outside of their primary household, children were commonly around dogs, cats, and creole chickens that were at their relatives' homes, both inside and outside. In some cases, relatives owned animals that were not owned or present at the child's household.

> *"…At my mom's house, she has like nine dogs and like two cats. So [my child] is over there, and my sister brings her up so she spends time with the dogs and playing with my nephews that are also there."*
>
> -age 22, urban community, owned one cat

Similar to trends in children's homes, cats were regularly present at other locations such as relatives' households and parks. Dogs were most common across all other locations where children spent time. Creole chickens, pigs, horses and rabbits were discussed by a few mothers in semi-rural and rural communities.

Presence and management of environmental contamination in other non-household locations

Indoor fecal contamination in other locations was similar to indoor contamination at children's homes: infrequent and largely from shoes or objects. Fecal contamination inside relatives' homes via shoes was reported in all communities, except for remote river villages. Mothers did not provide substantial details related to the presence and management of environmental contamination in others locations, presumably because mothers were not always present or supervising children in these locations.

Outdoor fecal contamination was more common. Across all communities, most observed dog feces in front or backyards of relatives' households or in the street where children played. The frequency at which dog feces was observed varied from regularly, sometimes, to rarely. Cat feces was discussed by a few mothers. The presence of creole chicken and pig feces was also reported by some, mostly in rural communities.

Extended family members who interacted with children regularly, but did not live in the primary household, had contact with animals they owned and animal feces. Siblings and family members who live with the child also had contact with animals at other locations, including at family members' houses and outdoor bingo gatherings. Mothers and grandparents cleaned up dog feces or feces from unspecified animals from around grandparents' houses where children play.

Child behaviors and interactions in other non-household locations

Child behaviors and interactions at home were quite different than those in other locations for some. For example, one rural road community child played in a garden by the river outside their grandmother's house, compared to largely playing indoors at the primary household.

> *"It is different because she is not inside the house there…She goes to the river side and sits and observes, searches for stones, throws stones to the river, things like that…*
>
> -age 39, rural road communities, non-animal owner

Direct child contact with animals in other locations was reported by few, mostly at relatives' or neighbors' houses. Children were reported to play with dogs and cats. One mother called attention to the potential negatives of her child having direct contact with animals:

> *"… [the child plays with the dog] because he likes it more, but when he plays more, he tends to put his fingers in his mouth so I wash his hands."*
>
> -age 19, semi-rural community, non-animal owner

Mothers reported that children played supervised in other locations; it was uncommon for children to be unsupervised. However, mothers were not always present, leaving siblings, relatives, and neighbors to care for the child. Some children played outside "sometimes" or "not often" while most did so regularly. Children played with various toys that belonged to others (e.g., relatives, other children), as well as surface water, rocks, soil/mud, and sand. One child played a game called "stars," which included finding bottle caps in the outdoor environment and playing with them. No major differences were seen by community type, aside from urban community children playing outdoors less often.

2.5. Discussion

By using go-along IDIs, we were able to disentangle the complex community, household, and child factors that influence exposure to zoonotic enteric pathogens. We found that animals and animal feces were ubiquitous – regardless of animal ownership – due to animal husbandry and feces management practices. Sixty-six percent of households had access to improved drinking water sources and 81% had improved sanitation facilities, yet all mothers reported opportunities for their child to be exposed to animal feces. Our findings emphasize that intervening on transmission of enteric pathogens will require integrated programming that targets human and animal feces. Below we highlight three key findings to consider for future research: (1) there are opportunities for exposure in settings outside of the household, (2) there are various caregivers and actors who play a role in child exposure, and (3) there are animal husbandry and feces management practices that influence animal fecal contamination of the environment.

Children visited and spent time in multiple locations on a typical day where animals and animal feces were present. Dogs, cats, and creole chickens that roamed freely contributed to fecal contamination at neighbors' and family members' homes, parks, and outdoor bingo gatherings. Dog and cat feces are main sources of toxocariasis in humans, which is among the top five neglected parasitic diseases and commonly occurs in young children.[50-52] In Turkey and Portugal, the presence of dog and cat feces in parks was associated with *Toxocara* spp. eggs in soil and sand.[53,54] In Sri Lanka, visiting a playground frequently and dogs having access to playgrounds were associated with increased risk of *Toxocara*

infection among children.[55] Studies in Ecuador found evidence of transmission of *Campylobacter jejuni* (*C. jejuni*) between dogs, cats, and children in the same household, and *Giardia* and atypical enteropathogenic *Escherichia coli* (aEPEC) between dogs and children.[56,57] No studies have investigated exposure related to free-range chicken feces in public spaces,[28] but studies in Peru, Ecuador, Cambodia, and Egypt found that the presence of chickens and their feces in domestic environments was associated with child infection with *Campylobacter* spp.[56-59] and *Cryptosporidium* spp.,[60] among others. Our findings suggest that sole focus on the household environment provides inaccurate and/or incomplete data because other significant locations where children may be exposed to zoonotic enteric pathogens are missed. A better understanding of where and how children are exposed across multiple settings will be critical to effectively assess and intervene on zoonotic exposures.

Child behavior and environments were primarily experienced through and determined by their caregivers, which included mothers and other individuals. In most cases, mothers were the primary caregiver, making them a significant mediator of child exposure to animal feces as demonstrated by research on other types of child exposure.[43,44,61-69] Maternal contact with animal feces, which was common, could result in child exposure through increased contamination on mothers' hands. In India, removing feces without using scoops or a similar tool was associated with increased hand contamination.[70,71] In Bangladesh, children of mothers with visibly dirty hands had elevated markers of environmental enteropathy,[72] which is associated with stunting and is thought to arise from repeat enteric infections.[73] Children in this study were also cared for by other people (e.g., siblings, grandparents, and neighbors) who had regular contact with animals and animal feces, highlighting that mothers and other individuals are key parts of the child environment and can influence exposure. Current approaches to exposure assessment and intervention that primarily focus on mothers may be insufficient. Identifying the various caregivers and actors who frequently interact with children could elucidate how multiple individuals mediate child exposure, and present significant opportunities for intervention.

Children were proximal to animals and animal feces, regardless of household animal ownership, because of husbandry practices at their household and in their community. Animal owners often let their dogs, cats, and creole chickens roam freely to scavenge for food, which also resulted in the presence of animal feces in or near their household. A study in rural Uganda found that households with free-roaming poultry had more feces in the household environment compared to those without free-roaming poultry.[27] In Ethiopia, more animal feces was present and child hands were dirtier in households where chicken coops were close to the home, not enclosed, and lacked fencing.[32] We found that free-range husbandry of dogs, cats, and creole chickens was a norm practiced by many in the study area, which allowed animals to move from compound to compound and defecate in or near households that did and did not own animals. Our findings highlight that child exposure to enteric pathogens in animal feces is not only influenced by the husbandry practices at their household, but also by the practices of others in their community. Programming that targets household level husbandry practices may be inadequate to reduce child exposure to animal feces, particularly if husbandry practices that contaminate the environment are norms practiced by many.

Animal feces management practices, beyond removal and disposal, contributed to fecal contamination of the household and surrounding environment. Animal feces on floors or in soil near child domestic and play areas were removed the majority of the time, but surfaces were inconsistently cleaned with soap or disinfectants after removal. A study in rural India found that increased environmental fecal contamination remains after feces are removed,[70] posing a risk to children when contaminated areas are not cleaned. The locations where mothers reported disposing of feces, such as rinsing feces into drains or ditches and throwing feces into surrounding areas, have been shown to increase contamination of the environment[70,71,74] and can enable transmission through various pathways. Rinsing feces with water can spread fecal contamination rather than eliminating it and throwing feces into surrounding areas can lead to increased exposure risks from flies, animals, or rain. This suggests that practices in one household could impact the environmental contamination and exposure of children in neighboring households.

The animal feces management practices identified in this study are similar to child feces management practices reported elsewhere,[69-71,74] including among mothers in the ECoMiD cohort.[69] Research on child feces management suggests that unsafe practices along the feces management pathway – which includes defecation, feces removal and disposal, defecation location cleaning, anal cleansing, and handwashing – increase environmental contamination.[69-71,74] Our findings demonstrate that animal feces contaminate the environment along a similar pathway. Identification and incorporation of safe practices along the animal feces management pathway, similar to those developed for child feces management (e.g., feces removed using a tool, feces safely deposited and contained in a latrine, defecation location cleaned with soap and water),[74] may be an effective, practical approach for intervening on the multiplicity of exposure pathways from various animal sources.

Strengths and Limitations

This study used rigorous qualitative methods (i.e., analyzing verbatim transcripts, double coding transcripts, systematic debriefing, and assessment and achievement of meaning and code saturation) that strengthen the validity of findings.[38,39,75,76] Sample sizes were uneven across communities due to circumstances surrounding COVID-19, which could impact quality of community comparisons. Additionally, reliance on mothers may have biased our findings because they were not always the main or sole caregiver on a typical day and could have provided incomplete or inaccurate information about their child. Still, the use of go-along IDIs enabled simultaneous in-depth interviewing and observation of the child's environment, which ascertained key details that were not reliant on maternal reporting. Reflections, observations, and analyzes conducted by author BCA, who is an experienced local researcher and conducted the interviewers, provided further insights that enhanced the credibility of community comparisons and information provided by mothers.[38,75]

Conclusions

Findings revealed that children may be exposed to zoonotic enteric pathogens through a variety of pathways in many locations and from multiple animal sources, regardless of whether or not their

household owned animals. Animal feces management practices were consistent with unsafe child feces management practices reported in other studies,[69,70,74] indicating that animal feces contamination in the environment may persist even if it is physically removed from the location where an animal defecated. To establish safe animal feces management practices, future research should assess unsafe practices and feces contamination along the management pathway established for child feces using surveys, observation or spot checks, and environmental sampling. The management pathway established for child feces can inform data collection at key points to validate the animal feces management pathway, with changes made as relevant. Building upon existing research on the child feces management pathway[70,71,74] will enable the development of an integrated exposure assessment and control approach that captures the many enteric pathogen exposure pathways related to animal and child feces. Differences by animal type will be important to consider because different types of animals defecate at different frequencies, have different types and sizes of stool, and may or may not bury their feces. Factors such as these impact removal and disposal practices, and have implications for environmental contamination.

2.6. References

1. Barredo L, Agyepong I, Liu G, Reddy S. Ensure healthy lives and promote well-being for all at all ages. *UN Chronicle*. 2015;51(4):9-10.

2. Hug L, Alexander M, You D, Alkema L, for Child UI-aG. National, regional, and global levels and trends in neonatal mortality between 1990 and 2017, with scenario-based projections to 2030: a systematic analysis. *The Lancet Global Health*. 2019;7(6):e710-e720.

3. Lozano R, Fullman N, Abate D, et al. Measuring progress from 1990 to 2017 and projecting attainment to 2030 of the health-related Sustainable Development Goals for 195 countries and territories: a systematic analysis for the Global Burden of Disease Study 2017. *The lancet*. 2018;392(10159):2091-2138.

4. Paulson KR, Kamath AM, Alam T, et al. Global, regional, and national progress towards Sustainable Development Goal 3.2 for neonatal and child health: all-cause and cause-specific mortality findings from the Global Burden of Disease Study 2019. *The Lancet*. 2021;398(10303):870-905.

5. Lanata CF, Fischer-Walker CL, Olascoaga AC, et al. Global Causes of Diarrheal Disease Mortality in Children <5 Years of Age: A Systematic Review. *PLOS ONE*. 2013;8(9):e72788. doi:10.1371/journal.pone.0072788

6. Lunn P. The impact of infection and nutrition on gut function and growth in childhood. *Proc Nutr Soc*. 2000;59:147.

7. Lunn PG. Growth retardation and stunting of children in developing countries. *British Journal of Nutrition*. 2002;88(2):109-110.

8. Guerrant RL, Oria RB, Moore SR, Oria MO, Lima AA. Malnutrition as an enteric infectious disease with long-term effects on child development. *Nutr Rev*. Sep 2008;66(9):487-505. doi:10.1111/j.1753-4887.2008.00082.x.

9. Guerrant RL, DeBoer MD, Moore SR, Scharf RJ, Lima AA. The impoverished gut--a triple burden of diarrhoea, stunting and chronic disease. *Nat Rev Gastroenterol Hepatol*. Apr 2013;10(4):220-9. doi:10.1038/nrgastro.2012.239.

10. Keusch GT, Denno DM, Black RE, et al. Environmental Enteric Dysfunction: Pathogenesis, Diagnosis, and Clinical Consequences. *Clin Infect Dis*. 2014:S207-12. vol. Suppl 4.

11. Petri WA, Jr., Miller M, Binder HJ, Levine MM, Dillingham R, Guerrant RL. Enteric infections, diarrhea, and their impact on function and development. *J Clin Invest*. Apr 2008;118(4):1277-90. doi:10.1172/jci34005.

12. Kane AV, Dinh DM, Ward HD. Childhood malnutrition and the intestinal microbiome. *Pediatric research*. 2015;77(1):256-262.

13. Reiner RC, Wiens KE, Deshpande A, et al. Mapping geographical inequalities in childhood diarrhoeal morbidity and mortality in low-income and middle-income countries, 2000–17: analysis for the Global Burden of Disease Study 2017. *The Lancet*. 2020/06/06/ 2020;395(10239):1779-1801. doi:https://doi.org/10.1016/S0140-6736(20)30114-8

14. Prüss-Ustün A, Wolf J, Bartram J, et al. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. *International journal of hygiene and environmental health*. 2019;222(5):765-777.

15. Wagner EG, Lanoix JN, Organization WH. *Excreta disposal for rural areas and small communities*. World Health Organization; 1958.

16. Eisenberg JN, Trostle J, Sorensen RJ, Shields KF. Toward a systems approach to enteric pathogen transmission: from individual independence to community interdependence. *Annual review of public health*. 2012;33:239.

17. Pickering AJ, Ercumen A, Arnold BF, et al. Fecal Indicator Bacteria along Multiple Environmental Transmission Pathways (Water, Hands, Food, Soil, Flies) and Subsequent Child Diarrhea in Rural Bangladesh. *Environmental Science & Technology*. 2018/07/17 2018;52(14):7928-7936. doi:10.1021/acs.est.8b00928.

18. Penakalapati G, Swarthout J, Delahoy MJ, et al. Exposure to Animal Feces and Human Health: A Systematic Review and Proposed Research Priorities. *Environmental science & technology*. 2017;51(20):11537-11552. doi:10.1021/acs.est.7b02811.

19. Prendergast AJ, Gharpure R, Mor S, et al. Putting the "A" into WaSH: a call for integrated management of water, animals, sanitation, and hygiene. *The Lancet Planetary Health*. 2019;3(8):e336-e337.

20. Sclar GD, Penakalapati G, Amato HK, et al. Assessing the impact of sanitation on indicators of fecal exposure along principal transmission pathways: a systematic review. *International journal of hygiene and environmental health*. 2016;219(8):709-723.

21. Wolf J, Hubbard S, Brauer M, et al. Effectiveness of interventions to improve drinking water, sanitation, and handwashing with soap on risk of diarrhoeal disease in children in low-income and middle-income settings: a systematic review and meta-analysis. *The Lancet*. 2022;400(10345):48-59.

22. Pickering AJ, Null C, Winch PJ, et al. The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health*. 2019;7(8):e1139-e1146.

23. Cumming O, Cairncross S. Can water, sanitation and hygiene help eliminate stunting? Current evidence and policy implications. *Maternal & child nutrition*. 2016;12:91-105.

24. Cumming O, Arnold BF, Ban R, et al. The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. *BMC medicine*. 2019;17(1):1-9.

25. Berendes DM, Yang PJ, Lai A, Hu D, Brown J. Estimation of global recoverable human and animal faecal biomass. *Nature Sustainability*. 2018;1(11):679-685.

26. Delahoy MJ, Wodnik B, McAliley L, et al. Pathogens transmitted in animal feces in low- and middle-income countries. *International Journal of Hygiene and Environmental Health*. 2018/05/01/ 2018;221(4):661-676. doi:https://doi.org/10.1016/j.ijheh.2018.03.005.

27. Lowe J, Ercumen A, Prottas C, Harris AR. Exploring the determinants and indicators of poultry feces management behaviors in rural Western Uganda. *The Science of the total environment*. 2022;834:155202-155202. doi:10.1016/j.scitotenv.2022.155202.

28. Ballard AML, Nick; Haardoerfer, Regine; Freeman, Matthew C; Levy, Karen; Caruso, Bethany A. Measurement in the study of human exposure to animal feces: A systematic review and audit. osf.io/d2nxc.

29. Zambrano LD, Levy K, Menezes NP, Freeman MC. Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. Jun 2014;108(6):313-325. doi:10.1093/trstmh/tru056.

30. Harvey SA, Winch PJ, Leontsini E, et al. Domestic poultry-raising practices in a Peruvian shantytown: implications for control of Campylobacter jejuni-associated diarrhea. *Acta Tropica*. 4// 2003;86(1):41-54. doi:http://dx.doi.org/10.1016/S0001-706X(03)00006-8.

31. Ercumen A, Prottas C, Harris A, Dioguardi A, Dowd G, Guiteras R. Poultry ownership associated with increased risk of child diarrhea: cross-sectional evidence from Uganda. *The American Journal of Tropical Medicine and Hygiene*. 2020;102(3):526.

32. Passarelli S, Ambikapathi R, Gunaratna NS, et al. The role of chicken management practices in children's exposure to environmental contamination: a mixed-methods analysis. *BMC public health*. 2021;21(1):1-15.

33. Hailemichael A, Gebremedhin B, Tegegne A. Status and drivers of village poultry production and its efficiency in Ethiopia. *NJAS: Wageningen Journal of Life Sciences*. 2017/12/01 2017;83(1):30-38. doi:10.1016/j.njas.2017.09.003.

34. Lee GO, Eisenberg JNS, Uruchima J, et al. Gut microbiome, enteric infections and child growth across a rural–urban gradient: protocol for the ECoMiD prospective cohort study. *BMJ Open*. 2021;11(10):e046241. doi:10.1136/bmjopen-2020-046241.

35. City Population: Republic of Ecuador, 2010 census. https://www.citypopulation.de/en/ecuador/.

36. Lee GO, Whitney HJ, Blum AG, et al. Household coping strategies associated with unreliable water supplies and diarrhea in Ecuador, an upper-middle-income country. *Water research*. 2020;170:115269-115269. doi:10.1016/j.watres.2019.115269.

37. Smith SM, Montero L, Paez M, et al. Locals get travellers' diarrhoea too: risk factors for diarrhoeal illness and pathogenic Escherichia coli infection across an urban-rural gradient in Ecuador. *Tropical Medicine & International Health*. 2019;24(2):205-219. doi:https://doi.org/10.1111/tmi.13183.

38. Hennink M, Hutter I, Bailey A. *Qualitative Research Methods*. SAGE Publications, Inc.; 2010.

39. Hennink MM, Kaiser BN, Marconi VC. Code Saturation Versus Meaning Saturation: How Many Interviews Are Enough? *Qual Health Res*. Mar 2017;27(4):591-608. doi:10.1177/1049732316665344.

40. Garcia CM, Eisenberg ME, Frerich EA, Lechner KE, Lust K. Conducting go-along interviews to understand context and promote health. *Qual Health Res*. Oct 2012;22(10):1395-403.

41. Carpiano RM. Come take a walk with me: the "go-along" interview as a novel method for studying the implications of place for health and well-being. *Health Place*. Mar 2009;15(1):263-72. doi:10.1016/j.healthplace.2008.05.003.

42. United Nations Children's Fund NY, NY. *Strategy for Improved Nutrition of Children and Women in Developing Countries. A UNICEF Policy Review*. ERIC Clearinghouse; 1990.

43. Rao N, Gazdar H, Chanchani D, Ibrahim M. Women's agricultural work and nutrition in South Asia: From pathways to a cross-disciplinary, grounded analytical framework. *Food Policy*. 2019/01/01/ 2019;82:50-62. doi:https://doi.org/10.1016/j.foodpol.2018.10.014.

44. Kadiyala S, Harris J, Headey D, Yosef S, Gillespie S. Agriculture and nutrition in India: mapping evidence to pathways. *Annals of the New York Academy of Sciences*. 2014;1331(1):43-56. doi:10.1111/nyas.12477.

45. Black MM, Lutter CK, Trude AC. All children surviving and thriving: re-envisioning UNICEF's conceptual framework of malnutrition. *The Lancet Global Health*. 2020;8(6):e766-e767.

46. McMahon SA, Winch PJ. Systematic debriefing after qualitative encounters: an essential analysis step in applied qualitative research. 2018-09-01 2018;doi:10.1136/bmjgh-2018-000837.

47. Davey JW, Gugiu PC, Coryn CL. Quantitative methods for estimating the reliability of qualitative data. *Journal of MultiDisciplinary Evaluation*. 2010;6(13):140-162.

48. O'Connor C, Joffe H. Intercoder reliability in qualitative research: debates and practical guidelines. *International journal of qualitative methods*. 2020;19:1609406919899220.

49. Hennink MM, Kaiser BN, Weber MB. What Influences Saturation? Estimating Sample Sizes in Focus Group Research. research-article. 2019;doi:10.1177_1049732318821692.

50. Ma G, Holland CV, Wang T, et al. Human toxocariasis. *The Lancet Infectious Diseases*. 2018;18(1):e14-e24. doi:10.1016/S1473-3099(17)30331-6.

51. Overgaauw PAM, van Knapen F. Veterinary and public health aspects of Toxocara spp. *Veterinary Parasitology*. 2013/04/15/ 2013;193(4):398-403.

52. Chen J, Liu Q, Liu G-H, et al. Toxocariasis: a silent threat with a progressive public health impact. *Infectious Diseases of Poverty*. 2018/06/13 2018;7(1):59. doi:10.1186/s40249-018-0437-0.

53. Gurler AT, Bolukbas CS, Akcay A, Pekmezci GZ, Acici M, Umur Ş. Role of cat and dog faeces in the contamination of sand playgrounds in public parks by Toxocara spp. *Medycyna Weterynaryjna*. 2020;76(08).

54. Otero D, Alho AM, Nijsse R, Roelfsema J, Overgaauw P, Madeira de Carvalho L. Environmental contamination with Toxocara spp. eggs in public parks and playground sandpits of Greater Lisbon, Portugal. *Journal of Infection and Public Health*. 2018;11(1):94-98.

55. Fernando S, Wickramasinghe V, Kapilananda G, Devasurendra R, Amarasooriya J, Dayaratne H. Epidemiological aspects and risk factors of Toxocariasis in a pediatric population in Sri Lanka. 2007.

56. Vasco K, Graham JP, Trueba G. Detection of Zoonotic Enteropathogens in Children and Domestic Animals in a Semirural Community in Ecuador. *Appl Environ Microbiol*. Jul 15 2016;82(14):4218-24. doi:10.1128/AEM.00795-16.

57. Lowenstein C, Vasco K, Sarzosa S, et al. Determinants of childhood zoonotic enteric infections in a semirural community of Quito, Ecuador. *The American journal of tropical medicine and hygiene*. 2020;102(6):1269.

58. Oberhelman RA, Gilman RH, Sheen P, et al. An Intervention-Control Study of Corraling of Free-Ranging Chickens to Control *Campylobacter* Infections Among Children in a Peruvian Periurban Shantytown. *Am J Trop Med Hyg*. 2006;74(6):6.

59. El-Tras WF, Holt HR, Tayel AA, El-Kady NN. Campylobacter infections in children exposed to infected backyard poultry in Egypt. *Epidemiol Infect*. Jan 2015;143(2):308-15. doi:10.1017/S095026881400096X.

60. Moore CE, Elwin K, Phot N, et al. Molecular Characterization of Cryptosporidium Species and Giardia duodenalis from Symptomatic Cambodian Children. *PLoS Neglected Tropical Diseases*. 2016;10(7).

61. Amugsi DA, Mittelmark MB, Lartey A, Matanda DJ, Urke HB. Influence of childcare practices on nutritional status of Ghanaian children: a regression analysis of the Ghana Demographic and Health Surveys. *BMJ Open*. 2014;4(11):e005340. doi:10.1136/bmjopen-2014-005340.

62. Majeed MT, Kiran F. Women's decision making power and child labor: evidence from Pakistan. *Quality & Quantity*. 2019/07/01 2019;53(4):2175-2197. doi:10.1007/s11135-019-00864-y.

63. Ghose B, Feng D, Tang S, et al. Women's decision-making autonomy and utilisation of maternal healthcare services: results from the Bangladesh Demographic and Health Survey. *BMJ Open*. 2017;7(9):e017142. doi:10.1136/bmjopen-2017-017142.

64. Millard AV. A causal model of high rates of child mortality. *Social Science & Medicine*. 1994;38(2):253-268. doi:10.1016/0277-9536(94)90395-6.

65. Mosley WH, Chen LC. An analytical framework for the study of child survival in developing countries. 1984. *Bulletin of the World Health Organization*. 2003;81(2):140-145.

66. Caruso B, Stephenson R, Leon JS. Maternal behavior and experience, care access, and agency as determinants of child diarrhea in Bolivia. *Revista panamericana de salud publica = Pan American journal of public health*. 2010;28(6):429-439. doi:10.1590/s1020-49892010001200004.

67. Po JYT, Bukania Z, Muhammad L, Hickey GM. Associations between Maternal Participation in Agricultural Decision-Making and Child Nutrition in Semiarid Kenya. *Journal of Hunger & Environmental Nutrition*. 2019:1-26. doi:10.1080/19320248.2019.1617214.

68. Björkman Nyqvist M, Jayachandran S. Mothers care more, but fathers decide: Educating parents about child health in Uganda. *American Economic Review*. 2017;107(5):496-500.

69. Sosa-Moreno A, Lee GO, Van Engen A, et al. Characterizing Behaviors Associated with Enteric Pathogen Exposure among Infants in Rural Ecuador through Structured Observations. *The American Journal of Tropical Medicine and Hygiene*. 2022;106(6):1747.

70. Bauza V, Majorin F, Routray P, Sclar GD, Caruso BA, Clasen T. Child feces management practices and fecal contamination: A cross-sectional study in rural Odisha, India. *Science of The Total Environment*. 2020/03/20/ 2020;709:136169. doi:https://doi.org/10.1016/j.scitotenv.2019.136169.

71. Majorin F, Torondel B, Routray P, Rout M, Clasen T. Identifying potential sources of exposure along the child feces management pathway: a cross-sectional study among urban slums in Odisha, India. *The American journal of tropical medicine and hygiene*. 2017;97(3):861.

72. George CM, Oldja L, Biswas SK, et al. Fecal Markers of Environmental Enteropathy are Associated with Animal Exposure and Caregiver Hygiene in Bangladesh. *Am J Trop Med Hyg*. Aug 2015;93(2):269-75. doi:10.4269/ajtmh.14-0694.

73. Kosek MN, Ahmed T, Bhutta Z, et al. Causal pathways from enteropathogens to environmental enteropathy: findings from the MAL-ED birth cohort study. *EBioMedicine*. 2017;18:109-117.

74. Mugel SG, Clasen TF, Bauza V. Global practices, geographic variation, and determinants of child feces disposal in 42 low-and middle-income countries: An analysis of standardized cross-sectional national surveys from 2016–2020. *International Journal of Hygiene and Environmental Health*. 2022;245:114024.

75. Franklin C, Ballan M. Reliability and validity in qualitative research. *The handbook of social work research methods*. 2001;4(273-292).

76. Maxwell J. Understanding and validity in qualitative research. *Harvard educational review*. 1992;62(3):279-301.

Chapter 3. Research Aim 2: Measurement in the study of human exposure to animal feces: A systematic review and audit[2]

3.1. Abstract

Background

Human exposure to animal feces is increasingly recognized as an important transmission route of enteric pathogens. Yet, there are no consistent or standardized approaches to measurement of this exposure, limiting assessment of the human health effects and scope of the issue.

Objective

To inform and improve approaches to the measurement of human exposure to animal feces, we audited existing measurement in low- and middle-income countries.

Methods

We systematically searched peer-reviewed and gray literature databases for studies with quantitative measures of human exposure to animal feces and we classified measures in two ways. First, using a novel conceptual model, we categorized measures into three 'Exposure Components' identified *a priori* (i.e., Animal, Environmental, Human Behavioral); one additional Component (Evidence of Exposure) inductively emerged. Second, using the exposure science conceptual framework, we determined where measures fell along the source-to-outcome continuum.

Results

We identified 1,428 measures across 184 included studies. Although studies overwhelmingly included more than one single-item measure, the majority only captured one Exposure Component. For example, many studies used several single-item measures to capture the same attribute for different animals, all of which were classified as the same Component. Most measures captured information about the source (e.g.

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animal presence) and contaminant (e.g. animal-sourced pathogens), which are most distal from exposure on the source-to-outcome continuum.

Discussion

We found that measurement of human exposure to animal feces is diverse and largely distal from exposure. To facilitate better assessment of the human health effects of exposure and scope of the issue, rigorous and consistent measures are needed. We recommend a list of key factors from the *Animal, Environmental,* and *Human Behavioral* Exposure Components to measure. We also propose using the exposure science conceptual framework to identify proximal measurement approaches.

3.2. Introduction

Exposure to animal feces and associated zoonotic pathogens are important threats to human health. An estimated 60% of human pathogens and 75% of emerging pathogens are zoonotic in origin.[1-4] Five pathogens that have the potential to be transmitted in animal feces (*Campylobacter*, non-typhoidal *Salmonella* (NTS), Lassa virus, *Cryptosporidium*, and *Toxoplasma gondii*) cause close to one million deaths annually, and four (NTS, enteropathogenic *E. coli*, *Campylobacter* spp., and *Cryptosporidium* spp.) are responsible for 28.3% of the 500,000 estimated global diarrhea deaths in children under five years.[5] Human exposure to such pathogens will increase as the global livestock and domestic animal population grows to meet human needs.[6] Global anthropogenic changes, such as more frequent human encroachment upon animals' natural habitats, have resulted in considerable zoonotic research on emerging diseases and spillover events where diseases are transmitted from animals to humans,[6-11] however the zoonotic burden of disease associated with animal feces is also substantial and warrants attention.[5]

Conditions and practices in low- and middle-income countries (LMICs) have been identified as particularly conducive for human exposure to animal-sourced fecal pathogens in the domestic environment.[1,2,6,12] Animals are an integral part of nutritional, agricultural, and trade practices in both

rural and urban areas[1-5] and small-scale animal agriculture is commonly promoted in development and nutrition intervention programs. Animals are often kept in close proximity to humans and their domestic environments, resulting in little separation of animals and their feces from humans, which can lead to fecal-oral transmission of enteric pathogens.[13-20] It is also common for many animals (e.g., chickens, dogs) to roam freely and defecate throughout public spaces.

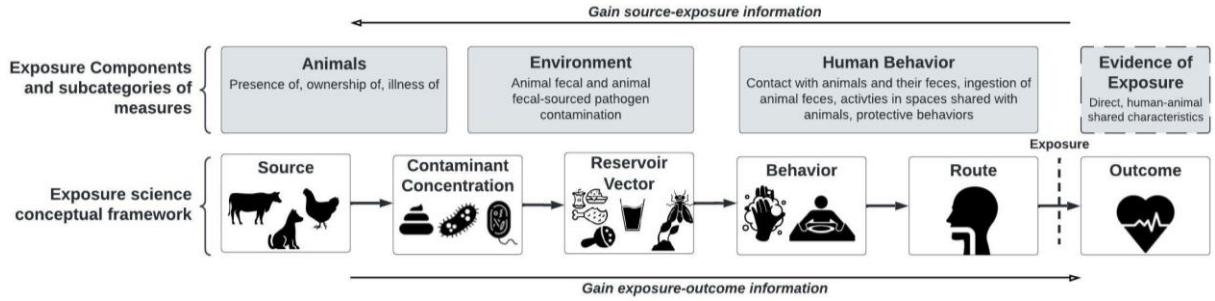
Significant challenges remain in assessing the impacts exposure to animal feces has on human health and the global burden of these health impacts. Such challenges are in part due to lack of clarity around and inconsistencies in measurement tools used to assess human exposure to animal feces. Ownership of animals, for example, has been used as a proxy to measure human exposure to animal feces[13,21-23] and, in some studies, simultaneously used as a proxy to measure benefits of animal ownership (i.e., increased animal-sourced food consumption).[16,24-26] Such an approach fails to make explicit what is being measured and may not capture the multidimensionality of, or many factors and conditions that contribute to, human exposure to animal feces (e.g., presence of animal feces in and around households, lack of adequate housing structures to separate animals and humans).

Human exposure to animal feces can be measured in several ways for varied types of animals, including via observation,[15,16,19,27,28] survey,[16,19,26,29] and microbiology techniques,[5,19,28] among others. Inconsistent and varied approaches, proxies, and methods limit comparisons across studies and settings, and ultimately inhibit researchers' ability to understand the burden of disease attributable to human exposure to animal feces. Therefore, there is a need to establish and improve measurement tools in the study of human exposure to animal feces.

Leveraging the exposure science source-to-outcome continuum—which includes source, contaminant, reservoir or vector, behavior, route, and outcome—will be advantageous for the clarification and standardization of measurement of human exposure to animal feces. Delineating the specific elements of exposure and the point at which feces enters the body elucidates what is critical to the measurement of

exposure and how one might develop more precise measurement approaches. Figure 3.1 depicts each part of the continuum with animal feces and associated zoonotic pathogens as the contaminants of interest. Transmission of zoonotic pathogens (i.e., the outcome) occurs when the feces of an infected animal (i.e., source) is ingested (i.e., route). Exposure can result from ingestion of feces contaminated food, fluids, fields, fomites, flies, and fingers (i.e., reservoirs or vectors), known as the F-diagram. Human interaction with reservoirs and vectors (i.e., behavior) is especially critical to the assessment of exposure to animal feces because humans play an active role in exposure through voluntary, or chosen, behaviors (e.g., touching animal feces, mouthing contaminated objects), as opposed to other exposures that result from involuntary behaviors (e.g., breathing contaminated air). For decades exposure scientists have demonstrated the important relationship between core exposure science concepts and measurement of environmental exposures. Specifically, research has found that assessment of the health effects of a particular contaminant greatly improve when more proximal measures of exposure are used, and measures of the source or contaminant are better for source evaluation and control.[30] For example, the measurement of animal fecal concentration on human hands and hand-to-mouth occurrences is more proximal to exposure and better estimates the amount of feces entering the body compared to the measurement of fecal concentration in fluids or fields, which provides little to no information about the magnitude of exposure. Past reviews and research priority papers have highlighted the importance of understanding and measuring various aspects of human exposure to animal feces, aligned with the source-to-outcome continuum, including the need to capture the various pathways and behaviors involved.[19,20,31] However, no study has reviewed existing measures to provide an appraisal of the quality and content of existing measures.

Figure 3.1. Conceptual model of human exposure to animal feces with Exposure Components identified a priori and Components that emerged from the data, and how they map to the source-to-outcome continuum



This systematic review serves to inform and improve approaches to the measurement of human exposure to animal feces by auditing existing measurement. We reviewed current types of animal fecal exposure assessed in human studies in LMICs and identified what measures have been used to evaluate human exposure to animal feces. We described what types of animals have been assessed, the health outcomes that have been evaluated, and the components of animal feces exposure that have been measured. We synthesized the properties of available measures using the source-to-outcome continuum and developed a conceptual framework for understanding and measuring exposure to animal feces that can be applied in future studies.

3.3. Methods

Search strategy

We conducted a systematic literature review to examine current types of animal feces exposure assessed in human studies and to identify what measures have been used in the evaluation of human exposure to animal feces. We followed standard methodology using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (see Appendix 6.1 Table S1) and registered our review with the International Prospective Register of Ongoing Systematic Reviews (PROSPERO; ID: CRD42021256986).

Our search built upon the systematic search conducted by Penakalapati *et al*. (2017) on October 3rd, 2016. To capture literature published after October 3rd, 2016, we updated the search using the same search string

(see Table 3.1 for the detailed generic search string), and additionally added three animal-related terms that were not included by Penakalapati *et al.* (2017) to capture papers published prior to and after their search date related to apes, monkeys, and bats. The generic search string was adapted to the specific database searched. We searched the following databases: PubMed, Web of Science Core Collection, Cochrane Library, EMBASE, and CAB Direct. Grey literature was searched from International Food Policy Research Institute, International Livestock Research Institute, Food and Agriculture Organization of the United Nations, U.S. Centers for Disease Control and Prevention Stacks, and the World Health Organization Institutional Repository for Information Sharing. We also hand-searched references of other relevant review papers. No publication date restrictions were used. Our search was conducted on July 13th, 2022.

Table 3.1. Generic search string where animals, feces, exposure, and human terms were combined using the Boolean operator "AND"

Category	**Generic search string**
Animals	animals OR animal OR zoonotic OR zoonosis OR "domestic animal" or "domestic livestock" OR livestock OR "animal husbandry" OR cattle OR cow OR bovine OR swine OR pig OR dog OR cat OR goat OR sheep OR poultry OR chicken OR fowl OR duck OR goose OR turkey OR mice OR rat OR murine OR rabbit OR horse OR "guinea pig" OR donkey OR "water buffalo" OR camel OR yak OR llama OR alpaca OR monkey* OR ape* OR bat*
Feces	feces OR faeces OR fecal OR faecel OR waste OR manure OR dung OR dropping
Exposure	exposure OR exposures OR contact OR contamination OR contaminate OR contaminated OR presence
Humans	human OR humans OR children OR child OR adult OR patients OR infant

*. Search terms added to the original terms used in Penakalapati *et al*. (2017)

Study eligibility

Publications were eligible for inclusion if they included a measure to evaluate human exposure to animal feces and included one or more of the following: (1) human exposure to poorly managed animal feces (e.g., feces not contained or separated from domestic or public spaces); (2) negative human health outcomes from animal feces exposures (e.g., diarrhea, trachoma, child growth outcomes, infection by

zoonotic pathogens); or (3) animal fecal contamination of the environment in locations where human exposure was possible (e.g., animal feces in public squares or at playgrounds). Penakalapati *et al*. (2017) used inclusion criteria 1-3 so all full-text papers included in their review were assessed for eligibility for this review. We leveraged the same definitions for poorly managed feces and human exposure to animal feces as those used in Penakalapati *et al* (2017). Poorly managed feces was defined as any animal feces that are not contained or separated from human domestic and/or public spaces. Human exposure to animal feces was defined as any behaviors related to handling animal feces (e.g., removing feces from domestic spaces or spreading animal manure on fields) or human activity conducted in close proximity to animals and their feces (e.g., children playing on the ground where animals also roam).

Experimental and observational studies were eligible for inclusion, including cross-sectional, case-control, longitudinal, and cohort studies. Qualitative studies were excluded, though mixed methods studies were included if they quantitatively reported on human exposure to animal feces. Review articles, conference proceedings, meeting abstracts, and book reviews were excluded. Additionally, we excluded studies if they were conducted in an occupational or industrial setting or took place in a high-income country, based on the World Bank's June 2020 classification.[32] LMICs were the focus of this review because sanitation and water infrastructure may be limited or nonexistent in such settings, potentially increasing the risk of human exposure to uncontained animal feces. Antibiotic resistance, epidemiology and etiology of zoonotic pathogens, and animal shedding of zoonotic fecal pathogens were beyond the scope of this review and articles focused exclusively on these topics were therefore excluded. Publications that discussed human respiratory health outcomes or diseases related to exposure to insect feces (e.g., Chagas disease) also were excluded. We included articles published in either English or Spanish.

Search results were catalogued, organized, and de-duplicated in Zotero[33] and then uploaded to Covidence.[34] Two of the study authors (AMB, NL) conducted title/abstract screening for an initial 150 publications of 6,931 to ensure consistency in inclusion and exclusion for full-text review. The remaining

search results (*n*=6,781) were divided among the two reviewers for title/abstract screening. The same two reviewers then independently determined if the full-text articles met inclusion criteria. When the two reviewers had conflicting decisions throughout the process, they debriefed and resolved the conflict.

Data extraction and synthesis

The authors who reviewed all the articles for inclusion (AMB, NL) also led the data extraction, first independently extracting data from 45 studies to standardize and improve reliability and validity of extraction using a pre-piloted form that recorded research objectives, key findings, descriptions of study population, descriptions of health outcomes, and descriptions of methods. One reviewer (AMB) then completed extraction on the remaining eligible studies (*n*=139). The second reviewer (NL) completed double extraction with 20 of the 139 remaining studies; 65 or approximately 35% of included articles were therefore double extracted.

Specific information about exposure measures was extracted for each study, including where exposure assessment took place, what animals and zoonotic pathogens were included, reported theoretical and operational definitions for the exposure construct or abstract concept used to express human exposure to animal feces,[35] formative research conducted, and steps taken to contribute to the reliability and validity of measures. For theoretical definitions, we noted if authors included a statement that gave meaning to the concept or construct being measured that allowed it to be distinguished from other concepts. For operational definitions, we noted if authors included a statement that transformed the theoretical concept into observable events or something that can be measured.[35]

In order to be included, measures had to be specific to animals and could not be general indicators of human exposure to fecal contamination (e.g., presence of *E. coli*), unless authors clearly specified that the measure was a proxy for exposure to animal feces (e.g., Verdeja *et al*. [2019] reports capturing consumption of soil as a proxy for ingestion of animal feces). Measures that captured both animal and

human feces and were not specified as proxies were recorded during extraction separately and can be found in our publicly available dataset.[36]

Quality appraisal

We assessed the quality of all survey and observation measures using a scoring method based on measurement development theory,[35,37] Consensus-based Standards for the Selection of Health Measurement Instruments (COSMIN),[38] and a scoring system used by the evidence-based measures of empowerment for research on gender equality (EMERGE) team.[39]. Specifically, we assessed the reliability and validity of survey and observation measures, and whether or not they were informed by formative research. The total possible score ranged from 0-3 points, where measures could receive one point when reporting any information related to formative research or assessment of reliability or validity during the measurement development or assessment process. For example, a measure would receive one point toward its quality score in the validity category for reporting assessment of *at least* one type of validity (e.g., testing if the measure captures what it's intended to [construct validity][37]). We used this broad and flexible scoring approach due to the diversity in methods used to measure human exposure related to animal feces and the lack of gold standard measures against which to compare the measures assessed. Each measures' final score was categorized as low (0-1 points), medium (2 points), or high (3 points) quality.

Quality assessment was not conducted for geospatial and laboratory-based measures of exposure because each method and related measure had its own criteria for assessing validity and reliability. Instead, brief summaries of measures and methods used and any approaches used to establish reliability and validity were recorded, as relevant. For example, for validity and reliability related to geospatial measures, we looked for mention of data quality, justification for buffer distance, and construct validity, or if comparison of measures was mentioned, among other criteria. When environmental sampling occurred, sampling strategies were extracted, including information about any formative work described or conducted to select sample sites and if and how sample site selection was justified.

We did not assess studies' risk of bias as this review is an audit of measures.

Data synthesis

We classified measures in two ways, first by Exposure Components based on our conceptual model of human exposure to animal feces, then by the exposure science concept they captured using the source-to-outcome continuum. To classify measures by Exposure Components, we used a 'best-fit framework synthesis,' or a structured and mixed deductive and inductive approach that involves creating a conceptual model of *a priori* themes to categorize data and identifying additional themes during data synthesis based on data that do not fit within a pre-specified theme.[40,41] In our case, we identified three Exposure Components *a priori* (i.e., animals, environment, and human behavior) and derived a conceptual model of human exposure to animal feces based on exposure science principles and a review of existing literature (Figure 3.1). The conceptual model was used to categorize measurement data extracted from included studies by *Animal* factors (e.g., presence, number, and type of animals); *Environmental* factors (e.g., soil contaminated with animal-sourced pathogens or animal feces); and/or *Human Behavioral* factors (e.g., human contact with animals or their feces). This model provided a skeletal framework for different aspects of human exposure, then, as appropriate, we modified the initial framework inductively as new Components emerged from the data. During analyses, we identified one additional Component that was not proposed in our initial conception of exposure, which we hereafter refer to as '*Evidence of Exposure*' (e.g., human infected with pathogens that is only zoonotically transmitted). Once Components were finalized, measures were categorized into subcategories based on what type of information they captured. Figure 3.1 indicates subcategories we identified across Exposure Components. To classify measures by exposure science concepts, we used each measure's Component and sub-category to determine where the measure fell along the source-to-outcome continuum (i.e., the exposure science conceptual framework that includes source, contaminant and/or concentration, reservoir or vector, behavior, route, and outcome).[30]

3.4. Results

After the initial title/abstract screening, 692 full text articles were reviewed, 184 of which met the inclusion criteria (Figure 3.2). The majority of included studies were cross-sectional (80%, *n*=148) and conducted in Asia (40%, *n*=73) and Africa (36%, *n*=67) (see Table 3.2 for more details). The earliest publication was from 1988; 83% (*n*=152) of articles were published since 2015. Relevant characteristics of the publications included in this review are presented in Table S2 (Appendix 6.1). The number of studies published over time is presented in Figure S1 (Appendix 6.1).

Figure 3.2. PRISMA flowchart displaying the results from the literature search and screening

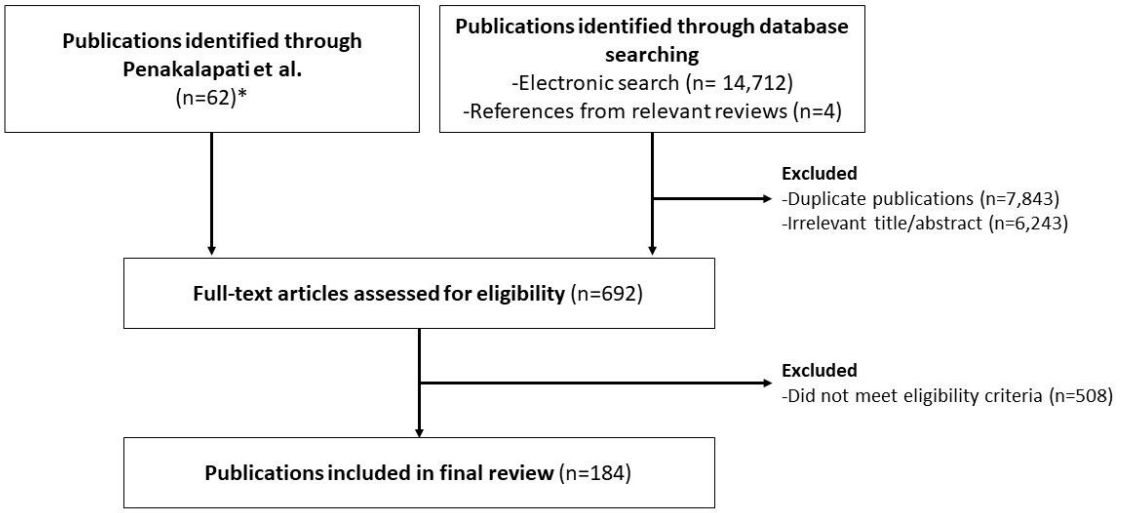


Table 3.2. Summary information about included studies (*n*=184)

	Number of studies *n* (%)
Region	
Asia	73 (40)
Africa	67 (36)
Central and South America	37 (20)
Europe	3 (2)
Oceania	1 (1)
Caribbean	1 (1)
Multiple regions	2 (1)
Study Design	
Cross-sectional	148 (80)
Cohort	16 (10)

Case-control	11 (6)
Randomized Control Trial	5 (3)
Other	5 (3)
Primary Research Focus	
Animal feces	98 (53)
Other	86 (47)
Target Study Population	
Children (and/or mother for child related outcome)	82 (45)
All individuals	48 (26)
Individuals with specific illness or risk factor	18 (10)
Adults	2 (1)
Non-human sample (e.g., animals, water samples)	34 (18)
Human Health Outcome*	
Pathogens found in stool	52 (35)
Diarrhea	10 (7)
Helminth, protozoan, bacteria, or virus seropositivity	10 (7)
Trachoma	4 (3)
Child growth	4 (3)
Environmental enteric dysfunction	1 (1)
Other	3 (2)
Multiple outcomes	32 (23)
None	34 (23)

*. *n*=150, only studies that enrolled human subjects

Most studies (54%, *n*=98) primarily focused on human exposure to animal feces, while others focused on other topics (e.g., contaminated drinking water) and included animal feces exposure measures as descriptive, contextual, or confounding variables. A majority (82%, *n*=150) enrolled human participants, with 45% (*n*=82) focused on children or samples related to children (e.g., mothers). The remaining studies captured non-human populations or samples (e.g., animals, environmental samples).

Among studies that enrolled human subjects (*n*=150), the most common health outcomes investigated were pathogens found in stool and diarrhea. Twenty-three percent (*n*=34) did not report any human health outcomes. Additional information about human health outcomes assessed and other study characteristics can be found in Table 3.2. All data are also available publicly on OSF.[36]

Theoretical and operational definitions of exposure

All but six studies (96.7%, *n*=178) referenced or used terminology to discuss human exposure to animal feces (e.g., “zoonotic transmission of pathogens,” “animal exposure”), yet only one study defined and

specified the bounds of the construct they sought to measure (i.e., a conceptual definition). Specifically, Barnes *et al*. (2018) provided a conceptual model of animal- and human-related factors that lead to human exposure, which guided their data collection and analysis. Barnes *et al*. (2018) described:

> "Since animal waste can contribute to water contamination and disease transmission, analyses included determinants related to the presence of domestic animals in the compound and the household. Variables were selected to represent potential exposure risks related to contact with domestic animals and rodent vectors. For the purposes of this research, animal contact was defined as: a) having direct interaction with an animal, animal waste, animal tissue or animal products; and b) sharing the same physical environment such as a home, yard/compound or community space."

Despite the absence of conceptual definitions, 15% (*n*=28) of studies described how they operationalized exposure. For example, Headey *et al*. (2017a) did not provide a conceptual definition but specified that hygiene spot-checks of animal feces in the exterior of the compound served as a proxy of exposure to animal feces.

Studies used undefined and varied terminology when referencing exposure, sometimes even within the same study, and were often imprecise in their detail. Many studies used the following or analogous phrases: "animal exposure," "exposure to animal feces," and/or "zoonotic transmission of pathogens". It was even common for authors to use these phrases interchangeably throughout the same manuscript. Studies also leveraged other terms or phrases to describe exposure such as "animal contact," "animal fecal contamination," "close proximity to animals and their feces," and "zoonotic exposure risks."

It was uncommon for researchers to provide the actual survey, observation questions, or tools that were used, and some studies used different language to describe the same measures throughout their paper. For example, one study described collecting 'existence of animals in households' via survey in the methods section and in tables, but reported 'contact with animals' in the written portions of the results and

discussion, making it unclear what measure and survey question was used. Another study reported asking participants if they lived with pets in the methods, but reported ‘contact with pets’ in the results.

Exposure measurement

Across all studies, we identified and extracted 1,428 measures. Studies overwhelmingly used multiple single-item measures (median number of measures per study = 5, interquartile range = 7), in contrast to indices that combine numerous indicators to make a composite variable. Some studies used several single-item measures to capture the same attribute across multiple types of animals (e.g., Thiem *et al.* [2012] measured the density of poultry, pigs, ruminants, dogs, and cats separately) while others measured multiple attributes for the same type of animal exposure separately (e.g., Gelli *et al*. [2019] measured the presence of chicken feces in the household compound and in food preparation areas). Microbiology (46%, *n*=660) and survey (39%, *n*=555) approaches were most common (Table 3.3). Other types of tools included observation, geospatial approaches, and animal fecal parasite shedding rates based on animal infection rates, animal fecal production rates, and animal population size in communities. Data for all measures are available in a public dataset on OSF.[36]

Exposure measurement was conducted for more than 40 types of animals (Appendix 6.1 Table S3). Most studies included multiple types of animals (69%, *n*=101). Dogs were the most common type, and were included in 43% of studies (*n*=79) and 25% of measures (*n*=359). Measurement was conducted principally within or around households (studies: 76%, *n*=137; measures: 80%, *n*=1140), including compounds with multiple households and shared courtyards. Other locations included public spaces, such as recreational parks, streets, or playgrounds (studies: 14%, *n*=26; measures: 14%, *n*=193*)*; villages or village fields (studies: 2%, *n*=3; measures: 3%, *n*=46*)*; and multiple locations (studies: 10%, *n*=18; measures: 3%, *n*=49). Additional information is provided in Table 3.3.

Table 3.3. Summary information about types of tools and quality of included measures

	Number of studies (*n*=184) *n (%)*	**Number of measures** (*n*=1,428) *n (%)*
Location of exposure measurement		
Household or compound (multiple households and shared courtyards)	140 (76)	1140 (80)
Public spaces (recreational parks, streets, or playgrounds)	26 (14)	193 (14)
Villages or village fields	3 (2)	46 (3)
Household or compound and public spaces	11 (6)	49 (3)
Household and villages or village fields	4 (2)	0 (0)
Type of animal(s)		
Cattle	65 (35)[b]	194 (14)
Cats	50 (27)	143 (10)
Chickens	45 (24)	149 (10)
Dogs	79 (43)	359 (25)
Goats	43 (23)	119 (8)
Pigs	39 (21)	105 (7)
Sheep	30 (16)	100 (7)
Other animals[a]	146 (79)	436 (31)
Not specified	77 (42)	215 (15)
Exposure Component captured		
Animal	59 (32)	831 (58)
Environmental	28 (15)	409 (29)
Human Behavioral	16 (9)	144 (10)
Evidence of Exposure	0 (0)	36 (3)
Multiple Components	81 (44)[c]	3 (<1)
Type of tool		
Microbiology	81 (44[b])	660 (46)
Survey	129 (70)	555 (39)
Observation	37 (20)	196 (14)
Other	3 (2)	17 (1)
Quality score *(n*=753)[d]		
Low (0-1)	--[e]	747 (>99)
Medium (2)	--	4 (<1)
High (3)	--	0 (0)

a. All included animals by study and measure can be found in Table S3

b. Percent adds to more than 100 because exposure measurement in most studies included multiple types of animals and used more than one measure captured by varied types of tools

c. 50 studies captured two components, 29 captured three, and two captured all four

d. Quality scores were only calculated for survey- and observation-based measures

e. Quality scores by study were not reported because most studies used more than one measure

Exposure Components

The majority of studies (56%, *n*=103) included measures from only one of our *a priori* identified Exposure Components. For example, Baker *et al.* (2018) used seven single-item measures that captured the presence of various types of animals and were therefore all classified in the *Animal* Exposure Component. No study included measures only from the Exposure Component that emerged during analyses, *Evidence of Exposure*. Table 3.4 provides a summary of Exposure Components and sub-categories measured.

Three studies included a measure that captured multiple Exposure Components.[67,87,88] For example, Sazzad *et al*. (2017) measured the presence of domestic animals, rodents, or rodent feces in households, capturing the presence of both animals (i.e., an *Animal* Component) and animal feces in the physical/natural environment (i.e., an *Environmental* Component). One study[67] leveraged an index that combined the number of animals, prevalence of zoonotic infection among animals, and daily fecal excretion of eggs by animal species and compared across five animal species to establish a relative transmission index.

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Table 3.4. Summary of Exposure Components and sub-categories measured across studies (*n* studies=184; *n* measures= 1,425)

Exposure Components and sub-categories	Studies *n* (%)	Measures *n* (%)	Measurement	Examples
1. Animal	138 (75)	831 (58)		
1.a. Presence of animals (owned and/or stray)	91(49)	337 (23)	-Presence/absence of animals	-Presence of ducks inside house [42-44]
			-Number of animals present	-Buffalo population in village[45]
			-Location of animals (sleep/corralled)	-Chicken in coop 90% of time[46]
			-Activity or space that animals occupy	-Livestock access primary water source[25,47]
			-Amount of time animal spends in specific location	-Number of minutes per 12 hours fowl present inside house[48]
1.b. Animal ownership	50 (20)	181 (13)	-Yes/no animals owned	-Household owns cattle[22,25,49]
			-Number of animals owned	-Number of sheep or goats owned[24,50]
			-Proportion of HHs that own animals	-Proportion of pig-owning households in village[21]
1.c. Animal illness or infection	46 (25)	313 (22)	-Yes/no animals ill/infected (lab-based)	-Dog Giardia infection[23,51,52]
			-Yes/no animals ill (symptom-based)	-Observed diarrheic calves[53]
			-At least one animal in flock/herd infected/sick	-At least one domestic animal in compound infected with *Campylobacter*[23,54]
2. Environmental	81 (44)	409 (29)		
2.a. Animal fecal contamination of the physical/natural environment	49 (27)	127 (9)	-Presence/absence animal fecal markers in environmental media (e.g., soil, water)	- Ruminant-associated fecal marker in public tubewells[55]

			-Presence/absence animal fecal markers on food	-Avian-associated fecal markers on food surface[56]
			-Presence/absence animal fecal markers on child toys	-Dog- or avian-associated fecal markers on child toys[57]
			-Concentration of animal fecal markers in environmental media	-Ruminant-associated fecal concentration in soil[58,59]
			-Presence of animal feces/floor plastered with feces	-Goat feces visible in household yard[60]
			-Number of animal stools	-Number of dog or cat stools at parks[61]
			-Frequency of finding animal feces	-Fresh rodent feces found daily or often[23]
			-Location of animal defecation	-Household dog defecates in street[62]
			-Animal feces eliminated/stored	-Cat feces cleaned from around household[63]
			-Frequency of animal fecal collection/removal	-Animal feces removed daily[25]
			-Method or location of animal feces/manure disposal/use	-Manure disposed of within residential area[23]
2.b. Animal fecal-sourced pathogen contamination of the physical/natural environment	35 (19)	263 (18)	-Presence/absence of pathogen(s) in animal feces in environmental media	-*Strongyloides stercoralis* in dog fecal samples[64,65]
			-Presence/absence of pathogen(s) on floor	-*E. coli* on kitchen floor[28]
			-Number/percentage of pathogen-positive animal fecal samples from environment	-Number of positive dog stool samples for intestinal nematode eggs[66]

			-Daily animal fecal-sourced pathogen excretion into environment	-Total daily *Schistosomiasis japonicum* egg excretion for buffalo[67]
			-Amount of animal fecal-source pathogens in environment	-Estimated environmental loading of Giardia cysts from sheep[68]
2.c. Animal fecal contamination of the interpersonal environment	7 (4)	8 (<1)	-Presence/absence animal feces or fecal markers on other person/caregivers' hands	-Ruminant-associated fecal markers on maternal hands[55,59]
			-Concentration of animal fecal markers on other person/caregivers' hands	-Ruminant-associated fecal concentration on maternal hands[55,59]
			-(No) handwashing after contact with animal feces	-Maternal handwashing after contact with animal feces[69]
2.d. Animal fecal contamination of the personal/bodily environment	6 (3)	11 (<1)	-Presence/absence animal feces or fecal markers on participant hands	-Avian-associated fecal markers on child hands[55,58]
			-Concentration of animal fecal markers on participant hands	-Ruminant-associated fecal concentration on child hands[70]
			-Number of times participant hands contaminated with animal feces	-Number of times child's hands were contaminated with poultry feces[48]
3. Human Behavioral	65 (35)	144 (10)*		
3.a. Contact with animals	37 (20)	71 (5)	-Contact/interaction with animals	-Contact with poultry[71]
			-Frequency of contact with animals	-Daily routine with livestock[72]
			-Contact with sick animals	-Personally caring for sick animals[73]
			-Activities with animals such as feeding, bathing, or tending to them	-Livestock exposure based on feeding, milking, bathing, or slaughtering[74]

3.b. Activities in spaces shared with animals	1 (<1)	7 (<1)	-Presence during activities such as feeding	-Child present during feeding of chickens[23]
			-Play in areas in compound where animals sleep	-Child play in areas in compound where cattle sleep[23]
			-Sleep in close proximity to where animals sleep	-Child sleeps >30 meters from where sheep sleep[23]
3.c. Contact with animal feces	18 (10)	32 (2)	-Contact/interaction with animal feces	-Contact with rabbit feces[42]
			-Frequency of contact with animal feces	-Frequency of hand-to-animal feces[75]
			-Use of or handling of animal dung, manure, or animal feces as fertilizer	-Family uses cow dung[76,77]
3.d. Ingestion of animal feces	7 (4)	12 (<1)	-Direct ingestion or mouthing of animal feces	-Child ingests chicken feces[28,69,78]
			-Number of times hands contaminated with animal feces put in mouth	-Number of times poultry feces contaminated hands were put in mouth[48]
3.e. Takes measures to avoid exposure	16 (9)	20 (1)	-Yes/no measures taken to avoid zoonotic disease(s)	-Takes measures to avoid rodent-borne disease[47]
			-Handwashing after contact with animals	-Child handwashing after pet contact[23]
			-Personal protective measures taken while having contact with animal feces	-Use of agricultural hoe to dispose of animal feces[79]
			-Frequency protective equipment worn or tools used while handling animal feces	-Wears gloves when cleaning dog feces all the time, sometimes, rarely, or never[80]

			-Prevention of animal fecal ingestion	-Mother able to stop child from eating soil or chicken feces[81]
4. Evidence of Exposure	14 (8)	41 (3)		
4.a. Human-animal shared characteristics	2 (1)	26 (2)	-Human and animal both infected with same pathogen(s)	-Child and dog from same household both positive for Giardia[82]
			-Relationship between pathogen(s) both human and animals are infected with	-*Campylobacter jejuni* clonal relationship of isolates from human and animal feces[83]
4.b. Direct	9 (5)	10 (<1)	-Positive for only zoonotically transmitted pathogen	-Human *Toxocara canis* infection[21,84,85]
4.c. Exposure**	1 (<1)	5 (<1)	-General animal exposure	-Exposure to adult dogs[86]

* Two measures captured contact with both animals and animal feces, therefore fitting into two subcategories. This measure was included in the total for *Human Behavioral* Component, but not included in the numeric counts for the subcategories

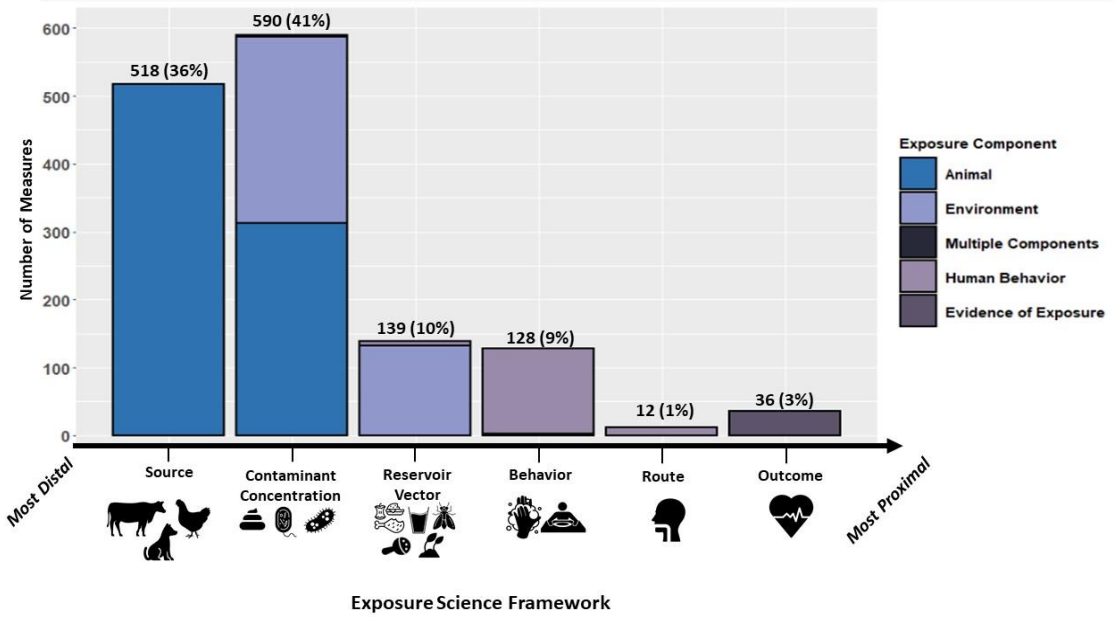
** These measures were categorized as *Evidence of Exposure* based on how they were reported, however no accompanying details about what exposure meant was included in the manuscript

+ 3 measures are not included as they indices that were a combination of multiple Components. They are described in-text (Results subsection 3.2.5).

Exposure science conceptual framework

Mapping measures to the exposure science conceptual framework based on their Exposure Component and sub-category revealed that most measures were distal from exposure (Figure 3.3). A majority (78%) captured information about source (i.e., animals) and the presence and/or concentration of contaminants (i.e., animal feces or pathogens of animal origin). Overall, moving along the source-to-outcome continuum and getting closer or more proximal to exposure, the number of measures in the literature decreases.

Figure 3.3. Number of measures along the exposure science conceptual framework (*n*=1,423)*



*Five measures of "exposure" to specific types of animals with no accompanying details about what exposure meant are not included

Properties of tools

On the scoring system we developed, 99% (*n*=744) survey and observation measures received quality scores of zero (83%, *n*=622) or one (16%, *n*=122) out of three, indicating they were low quality (see Methods section 2.4 for more details). Four measures (<1%) from two studies[89,90] received a score of two (i.e., they were of medium quality). Researchers described conducting formative research in the form of piloting or pre-testing tools and/or assessing convergent validity of the exposure measure after data

collection. No other types of formative research or validity assessments were reported, nor did any researchers directly state that examining relationships between the same concepts measured in different ways was being investigated to assess convergent validity. Reliability was only assessed for two measures in Gizaw *et al.* (2022), specifically by assessing internal consistency reliability.

Validity and reliability measurement methods reported by studies using geospatial (*n*=5) and environmental sampling-based (*n*=320) measures varied. Across the two studies that reported geospatial measures,[91,92] information on reliability and validity assessment was minimal. The studies provided information on buffer and grid cell sizes, but justification for size selection was not provided. Data quality was not discussed, no head-to-head comparisons of measures to assess construct validity were reported, and no procedures to assess reliability of measures were discussed. Few measures that were environmental sampling-based (7%, *n*=21) were preceded with formative research to inform or pilot sampling. However, most (70%, *n*=225) sampling locations or strategies were justified, meaning that the research question justified the selection of sampling locations.

3.5. Discussion

We audited measurements of human exposure to animal feces in studies in LMICs, where animals are vital and ownership is widely promoted in development and nutrition intervention programs.[15-17,93,94] Most of the existing measures identified in our systematic review were distal from exposure and did not account for the multiple causal conditions that constitute exposure, limiting comprehensive and precise exposure assessment.[30,37,95,96] Unsurprisingly, given the interdisciplinary nature of this topic, we also found considerable diversity in measurement approaches, which inhibits cross-study and cross-setting comparisons.[19] Findings from our review and audit provide considerations for improving measurement of human exposure to animal feces to facilitate better understanding of how animal fecal-related exposures affect human health and increase our ability to identify areas of highest risk for intervention. We offer four specific suggestions to improve measurement: (1) measure attributes from all of the Exposure Components to more comprehensively and accurately capture exposure, (2) measure proximal factors

along the source-to-outcome continuum to more precisely assess exposure, (3) develop and validate a measure to standardize measurement across studies, and (4) use standard reporting guidelines to increase transparency.

First, to increase the likelihood of comprehensively and accurately capturing animal feces exposure, measurement of attributes across all of the Exposure Components is needed. The majority of studies only captured one of the Exposure Components; only three studies captured all four. Human exposure to animal feces is a result of multiple factors within multiple Exposure Components,[97] and it has not yet been clearly demonstrated whether one particular Exposure Component, more than any other, affects human health or exerts an effect by itself. For example, animal- (e.g., animal presence/ownership, animal illness) and environment-related factors (e.g., presence of animal feces) may not consistently be good proxies for exposure if humans do not practice specific behaviors that expose them to animal-sourced contaminants. Conversely, animals and animal feces may still be present and result in exposure even when significant time is spent managing animals and their feces.[97] Only accounting for human behavioral factors does not capture whether animal-sourced contaminants are in fact present. Measuring attributes from multiple Exposure Components will facilitate more comprehensive and accurate assessment of human exposure and allow researchers to examine how the different Components, by themselves and collectively, impact health.

We propose an initial list of factors by Exposure Component from which items can be derived (Table 3.5) based on synthesis of existing measures and our conceptual model of human exposure to animal feces. We specifically include factors that can be measured using survey and observation methods because they are conducive to scalability and the creation of a multidimensional measure. We recommend that researchers capture at least one attribute or factor from the *Animal, Environmental,* and *Human Behavioral* Exposure Components. *Evidence of Exposure* is extremely beneficial to include but is not part of our recommendations because this Exposure Component cannot be measured via a survey or observation tool. We have identified presence of animals (*Animal* Component), presence of animal feces

(*Environmental* Component), human contact with animals (*Human Behavioral* Component), and human contact with animal feces (*Human Behavioral* Component) to be critical to the measurement of human exposure to animal feces. These four factors were selected because they are fundamental elements of human exposure to animal feces (i.e., exposure cannot occur without the presence of and human contact with animals and animal feces), can be assessed relatively easily via survey and observation, and are broadly applicable across populations and contexts. Additional factors, including those related to corralling and feces disposal practices identified by Lowe *et al.* (2022), may also be critical to or better at assessing human exposure to animal feces and warrant further investigation. As such, Table 3.5 includes other optional factors for researchers to consider based on their applicability to local contexts and specific populations. We do not provide suggestions for microbiology and spatial approaches given large variation in methods and their inability to capture information from the *Human Behavioral* Exposure Component. Researchers can examine, revise, and build upon this review and the preliminary list of factors in the measurement development process. We view this audit and initial list as a first step toward improving measurement and the creation of a standard, validated measure. In the meantime, researchers can derive items from Table 3.5 while validated measures are being created.

Table 3.5. Initial list of factors that capture the three Exposure Components of human exposure to animal feces with factors critical to measurement in bold face^

Component	**Factor**
Animal	-**Presence of animals** -Ownership of animals
Environmental - physical	**-Presence of animal feces** -Animal feces removal method -Collection and application of animal fecal fertilizer
Environmental – interpersonal	-Caregiver(s) contact with animals* -Caregiver(s) contact with sick animals -Caregiver(s) contact with animal feces -Caregiver(s) handwashing after various feces-related contact -Others in household work with animals -Others in household work with animal feces
Environmental – personal	-Hands contaminated with animal feces
Human Behavioral	**-Contact with animals** -Contact with sick animals **-Contact with animal feces**

	-Ingestion of animal feces -Contact with potentially fecally contaminated soil or sand -Ingestion of potentially fecally contaminated soil or sand -Contact with potentially fecally contaminated objects -Mouthing of potentially fecally contamination objects -Handwashing after various feces-related contact

^ This list of factors was generated specifically for survey and observation-based methods.
* Some factors may only be applicable based on the primary participant of the study. For example, caregiver factors may only applicable if children are primarily of interest.

Second, to ensure that more proximal exposure factors are captured, the exposure science conceptual framework should be used in tandem with the aforementioned Exposure Components. By mapping measures onto the source-to-outcome continuum, we show that a small proportion captured information about proximal exposure concepts (i.e., human behavior, route, or outcome). Further integration of human behavioral measurement into animal feces-related research is especially needed, as other researchers have pointed out,[15-17,19,26,98] given that only 9% of existing measures capture any human behaviors and that human behaviors play a central role in exposure to animal feces. Measuring more proximal factors will allow researchers to assess exposure more precisely, which will improve the accuracy of health effect estimates by reducing exposure misclassification.[30] Approaches will need to be multidisciplinary in nature. Specifically, there is opportunity for collaboration among researchers with expertise in psychometrics, behavioral science, and exposure science.

Third, to improve and standardize measurement across studies, development and validation of a multidimensional measure of human exposure to animal feces that can be used across settings is needed, similar to those developed for food, water, and sanitation insecurity.[99-102] The creation and validation of standard, multidimensional measures in other sectors has enabled and expanded researchers' and practitioners' ability to comprehensively measure constructs, assess public health issues within and across communities, and develop, implement, and measure the effectiveness of interventions.[103-106] Existing measures of human exposure to animal feces are diverse and largely capture one single attribute of exposure, despite the number of factors that constitute it. Creating and validating a multidimensional

measure of human exposure to animal feces that is scalable, generalizable, and cross-culturally equivalent will facilitate assessment of the burden of disease and intervention, policy, and program effectiveness. Using an index that is a composite of multiple indicators to capture exposure is advantageous as it will increase the likelihood of capturing the intended construct by facilitating measurement of all three Exposure Components that were identified *a priori* (i.e., *Animal, Environmental,* and *Human Behavioral*), decrease the likelihood of exposure misclassification, and allow researchers to assess relative intensity of and more granular variation in exposure. We recommend that researchers use the three stages of measurement development (i.e., item development, index development, and index evaluation) to create a rigorous index.[35,37,107-109] Interpretability, simplicity, and cross-cultural applicability should be prioritized so the measure can be used across settings and at scale.

Fourth, to mitigate current limitations in measurement related to reporting, increased transparency and standardized reporting among studies focused on quantitative measurement of human exposure to animal feces should be prioritized. Lack of transparency found in existing research serves as a barrier to clearly determining which methods were used to assess human exposure, what measures truly are, and what findings mean. Nearly all (98%) studies used terms or phrases related to exposure to animal feces, but few clearly defined or operationalized measures or provided survey and observation questions or tools. Assessment of measurement properties revealed that studies examining exposure were overwhelmingly missing key information that can permit other researchers from effectively assessing the quality of measures, as well as applying and/or building upon their approaches. We propose using the COSMIN Reporting Guideline's common recommendations for descriptions of measures, validity, and reliability[38] with the goal of increasing transparency, accuracy in measurement assessment, and researchers' ability to use measurement tools from literature. We summarize research and practice opportunities in Text Box 3.1.

Text Box 3.1. Research and measurement opportunities related to human exposure to animal feces

- **Measure attributes from all of the Exposure Components.** To increase the likelihood of comprehensively and accurately capturing human exposure to animal feces, we recommend capturing factors from each of the *Animal* (i.e., the presence of animals), *Environmental* (i.e., presence of animal feces), and *Human Behavioral* (i.e., contact with animals and contact with animal feces) Exposure Components. Ideally, factors will be measured using survey- and observation-based methods because they are conducive to scalability and the creation of a multidimensional measure. Measuring attributes from multiple Exposure Components will facilitate more comprehensive and accurate assessment of human exposure and allow researchers to examine how the different Components, by themselves and collectively, impact health.
- **Capture proximal exposure factors along the exposure science framework.** To more precisely measure exposure, researchers should use the exposure science conceptual framework in tandem with the Exposure Components to capture more proximal exposure factors. Further integration of human behavioral measurement is especially needed, given that human behaviors play a central role in exposure to animal feces. Measuring more proximal factors along the source-to-outcome continuum will allow researchers to triangulate exposure more precisely and better assess health effects of exposure, and will need to be multidisciplinary in nature.
- **Develop and validate a multidimensional measure that can be used across settings.** To improve and standardize measurement across studies, a validated index should be developed for the construct, 'human exposure to animal feces.' The measure should be a composite of multiple indicators (i.e., multidimensional), scalable, interpretable, and applicable or cross-culturally or adaptable to different cultures. Such a measure will improve researchers' and practitioners' ability to assess the burden of disease related to animal feces and intervention, policy, and program effectiveness.
- **Use standard reporting guidelines to improve and direct reporting of measurement properties.** To mitigate current limitations in measurement related to lack of transparency, standardized reporting should ideally be used. Studies should report descriptions of measures, validity, and reliability and provide measurement tools when possible. Using the COSMIN Reporting Guideline's common recommendations[38] would increase transparency, accuracy in measurement assessment, and researchers' ability to use measurement tools from the literature.

Strengths and Limitations

This review leveraged a 'best-fit framework synthesis,' a structured process that combines deductive and inductive approaches, resulting in a comprehensive and rigorous synthesis of measures used to capture human exposure to animal feces. We intentionally used a structured, but flexible, approach with broad inclusion criteria given the novelty of the review and desire to capture a large body of literature and range of measures. This meant that our inclusion criteria did not consider methodological rigor and therefore studies were included regardless of quality. However, part of our goal was to evaluate the rigor of the

field, therefore, including studies regardless of rigor was central to the purpose of this review. We were limited to studies written in English and Spanish, which could have missed some relevant articles. We also did not include studies that captured occupational human exposure to animal feces. Inclusion of such studies could provide important insights that could be applied to non-occupational exposure measurement, although many aspects of occupational exposure may be outside the scope of typical human exposure. Lastly, our approach may be biased toward public health literature and therefore be missing important studies from other disciplines, such as animal agriculture or economic development. Nevertheless, our search terms queried a wide-range of studies from many disciplines, which allowed us to review a variety of studies and measurement approaches.

Conclusion

Exposure to animal feces is a major cause of enteropathogen infection. Accurate, proximal measures of these exposures are crucial to assess their potential burden of disease and intervention, policy, and program effectiveness. We provide an overview of existing measures in the literature, synthesize them into a conceptual framework, and offer opportunities to improve research and measurement of human exposure to animal feces. Additional research is needed to create and validate a multidimensional measure, which can build upon our initial conceptual model of exposure and proposed list of factors to measure. As with other similar efforts to develop measures for important multi-faceted topics, researchers should use standardized reporting guidelines and include measurement tools in supplementary material when possible. We recommend that researchers measure the key factors in the *Animal, Environmental,* and *Human Behavioral* Exposure Components that we identified and outlined in Table 3.5 (i.e., presence of animals, presence of animal feces, contact with animals, and contact with animal feces) and concurrently use the exposure science conceptual framework to ensure that proximal exposure factors along the source-to-outcome continuum are captured.

3.6. References

1. Jones KE, Patel NG, Levy MA, et al. Global trends in emerging infectious diseases. *Nature*. 2008;451(7181):990-993.

2. Taylor LH, Latham SM, Woolhouse ME. Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences*. 2001;356(1411):983-989.

3. Woolhouse ME, Gowtage-Sequeria S. Host range and emerging and reemerging pathogens. *Emerging infectious diseases*. 2005;11(12):1842.

4. World Health Organization. *The control of neglected zoonotic diseases: community based interventions for NZDs prevention and control: report of the third conference organized with ICONZ, DFID-RiU, SOS, EU, TDR and FAO with the participation of ILRI and OIE: 23-24 November 2010, WHO Heaquarters, Geneva, Switzerland*. 2011. 9241502525.

5. Delahoy MJ, Wodnik B, McAliley L, et al. Pathogens transmitted in animal feces in low- and middle-income countries. *International Journal of Hygiene and Environmental Health*. 2018/05/01/ 2018;221(4):661-676. doi:https://doi.org/10.1016/j.ijheh.2018.03.005.

6. Grace D, Mutua F, Ochungo P, et al. Mapping of poverty and likely zoonoses hotspots. Zoonoses Project 4. Report to the UK Department for International Development. *International Livestock Research Institute, Nairobi, Kenya*. 2012.

7. Chomel BB, Belotto A, Meslin F-X. Wildlife, exotic pets, and emerging zoonoses. *Emerging infectious diseases*. 2007;13(1):6.

8. Coker RJ, Hunter BM, Rudge JW, Liverani M, Hanvoravongchai P. Emerging infectious diseases in southeast Asia: regional challenges to control. *The Lancet*. 2011;377(9765):599-609.

9. Coker R, Rushton J, Mounier-Jack S, et al. Towards a conceptual framework to support one-health research for policy on emerging zoonoses. *The Lancet infectious diseases*. 2011;11(4):326-331.

10. Cutler SJ, Fooks AR, Van der Poel WH. Public health threat of new, reemerging, and neglected zoonoses in the industrialized world. *Emerging infectious diseases*. 2010;16(1):1.

11. Wolfe ND, Dunavan CP, Diamond J. Origins of major human infectious diseases. *Nature*. 2007;447(7142):279-283.

12. Osbjer K, Boqvist S, Sokerya S, et al. Household practices related to disease transmission between animals and humans in rural Cambodia. *BMC Public Health*. May 09 2015;15:476. doi:10.1186/s12889-015-1811-5.

13. Barnes AN, Anderson JD, Mumma J, Mahmud ZH, Cumming O. The association between domestic animal presence and ownership and household drinking water contamination among peri-urban communities of Kisumu, Kenya. *PloS one*. 2018;13(6):e0197587-e0197587.

14. George CM, Oldja L, Biswas SK, et al. Fecal Markers of Environmental Enteropathy are Associated with Animal Exposure and Caregiver Hygiene in Bangladesh. *Am J Trop Med Hyg*. Aug 2015;93(2):269-75. doi:10.4269/ajtmh.14-0694.

15. Headey D, Nguyen P, Kim S, Rawat R, Ruel M, Menon P. Is Exposure to Animal Feces Harmful to Child Nutrition and Health Outcomes? A Multicountry Observational Analysis. *Am J Trop Med Hyg*. 2016. December 19, 2016. doi:10.4269/ajtmh.16-0270.

16. Headey D, Hirvonen K. Is Exposure to Poultry Harmful to Child Nutrition? An Observational Analysis for Rural Ethiopia. *PLoS One*. 2016;11(8)doi:10.1371/journal.pone.0160590.

17. Lambrecht NJ, Wilson ML, Jones AD. Assessing the Impact of Animal Husbandry and Capture on Anemia among Women and Children in Low- and Middle-Income Countries: A Systematic Review. *Advances in Nutrition*. 2019;10(2):331-344. doi:10.1093/advances/nmy080.

18. Ngure FM, Humphrey JH, Mbuya MNN, et al. Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *The American journal of tropical medicine and hygiene*. 2013;89(4):709-716. doi:10.4269/ajtmh.12-0568.

19. Penakalapati G, Swarthout J, Delahoy MJ, et al. Exposure to Animal Feces and Human Health: A Systematic Review and Proposed Research Priorities. *Environmental science & technology*. 2017;51(20):11537-11552. doi:10.1021/acs.est.7b02811.

20. Zambrano LD, Levy K, Menezes NP, Freeman MC. Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. Jun 2014;108(6):313-325. doi:10.1093/trstmh/tru056.

21. Boyko RH, Marie Harrison L, Humphries D, et al. Dogs and pigs are transport hosts of Necator americanus: Molecular evidence for a zoonotic mechanism of human hookworm transmission in Ghana. *Zoonoses and public health*. 2020;67(5):474-483.

22. Budge S, Barnett M, Hutchings P, et al. Risk factors and transmission pathways associated with infant Campylobacter spp. prevalence and malnutrition: a formative study in rural Ethiopia. *PloS one*. 2020;15(5):e0232541.

23. Conan A, O'Reilly CE, Ogola E, et al. Animal-related factors associated with moderate-to-severe diarrhea in children younger than five years in western Kenya: a matched case-control study. *PLoS neglected tropical diseases*. 2017;11(8):e0005795.

24. De Bruyn J, Thomson PC, Darnton-Hill I, Bagnol B, Maulaga W, Alders RG. Does village chicken-keeping contribute to young children's diets and growth? A longitudinal observational study in rural Tanzania. *Nutrients*. 2018;10(11):1799.

25. Gelli A, Headey D, Becquey E, et al. Poultry husbandry, water, sanitation, and hygiene practices, and child anthropometry in rural Burkina Faso. *Maternal & child nutrition*. 2019;15(4):e12818.

26. Kaur M, Graham J, Eisenberg JNS. Livestock Ownership among Rural Households and Child Morbidity and Mortality: An Analysis of Demographic Health Survey Data from 30 Sub-Saharan African Countries (2005-2015). *Am J Trop Med Hyg*. 2017:25. doi:10.4269/ajtmh.16-0664.

27. Bukenya GB, Nwokolo N. Compound hygiene, presence of standpipe and the risk of childhood diarrhoea in an urban settlement of Papua New Guinea. *International Journal of Epidemiology*. 1991;20(2):534-539.

28. Ngure FM, Humphrey JH, Mbuya MNN, et al. Formative Research on Hygiene Behaviors and Geophagy among Infants and Young Children and Implications of Exposure to Fecal Bacteria. *American Journal of Tropical Medicine and Hygiene*. 2013;89(4):709-716. doi:http://dx.doi.org/10.4269/ajtmh.12-0568.

29. Harvey SA, Winch PJ, Leontsini E, et al. Domestic poultry-raising practices in a Peruvian shantytown: implications for control of Campylobacter jejuni-associated diarrhea. *Acta Tropica*. 4// 2003;86(1):41-54. doi:http://dx.doi.org/10.1016/S0001-706X(03)00006-8.

30. National Research Council. Exposure science in the 21st century: a vision and a strategy. 2012.

31. Pickering AJ, Null C, Winch PJ, et al. The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health*. 2019;7(8):e1139-e1146.

32. World Bank. The World by Income and Region. World Development Indicators: The World Bank Group; 2022.

33. *Zotero*. https://www.zotero.org

34. *Covidence systematic review software*. www.covidence.org

35. de Vet HCW, Terwee CB, Mokkink LB, Knol DL. *Measurement in Medicine : A Practical Guide*. Cambridge University Press; 2011.

36. Ballard AM; Laramee N; Haardoerfer, R; Freeman, MC; Levy, K; Caruso, BA. Measurement in the study of human exposure to animal feces: A systematic review and audit. osf.io/d2nxc.

37. Boateng GO, Neilands TB, Frongillo EA, Melgar-Quiñonez HR, Young SL. Best Practices for Developing and Validating Scales for Health, Social, and Behavioral Research: A Primer. Review. *Frontiers in Public Health*. 2018-June-11 2018;6(149)doi:10.3389/fpubh.2018.00149.

38. Gagnier JJ, Lai J, Mokkink LB, Terwee CB. COSMIN reporting guideline for studies on measurement properties of patient-reported outcome measures. *Quality of Life Research*. 2021;30(8):2197-2218.

39. EMERGE Team. Scoring Methodology. https://emerge.ucsd.edu/scoring-methodology/

40. Carroll C, Booth A, Cooper K. A worked example of" best fit" framework synthesis: a systematic review of views concerning the taking of some potential chemopreventive agents. *BMC medical research methodology*. 2011;11(1):1-9.

41. Carroll C, Booth A, Leaviss J, Rick J. “Best fit” framework synthesis: refining the method. *BMC medical research methodology*. 2013;13(1):1-16.

42. Bern C, Kawai V, Vargas D, et al. The Epidemiology of Intestinal Microsporidiosis in Patients with HIV/AIDS in Lima, Peru. *The Journal of Infectious Diseases*. 2005;191(10):1658-1664. doi:10.1086/429674.

43. Harris AR, Pickering AJ, Harris M, et al. Ruminants Contribute Fecal Contamination to the Urban Household Environment in Dhaka, Bangladesh. *Environ Sci Technol*. May 3 2016;50(9):4642-9. doi:10.1021/acs.est.5b06282.

44. Reid B, Orgle J, Roy K, Pongolani C, Chileshe M, Stoltzfus R. Characterizing potential risks of fecal–oral microbial transmission for infants and young children in Rural Zambia. *The American Journal of Tropical Medicine and Hygiene*. 2018;98(3):816.

45. Daniels ME, Smith WA, Schmidt WP, Clasen T, Jenkins MW. Modeling Cryptosporidium and Giardia in Ground and Surface Water Sources in Rural India: Associations with Latrines, Livestock, Damaged Wells, and Rainfall Patterns. *Environ Sci Technol*. Jul 19 2016;50(14):7498-507. doi:10.1021/acs.est.5b05797.

46. Oberhelman RA, Gilman RH, Sheen P, et al. An Intervention-Control Study of Corraling of Free-Ranging Chickens to Control *Campylobacter* Infections Among Children in a Peruvian Periurban Shantytown. *Am J Trop Med Hyg*. 2006;74(6):6.

47. Suwannarong K, Chapman RS. Characteristics associated with contact with rodents in, around, and outside homes in Khon Kaen Province, Thailand. *Am J Trop Med Hyg*. Apr 2015;92(4):784-90. doi:10.4269/ajtmh.14-0195.

48. Marquis GS, Ventura G, Gilman RH, Porras E, Miranda E, et al. Fecal Contamination of Shanty Town Toddlers in Households with Non-Corralled Poultry, Lima Peru. *American Journal of Public Health*. Feb 1990;80(2):146-9.

49. Caron Y, Hong R, Gauthier L, et al. Stunting, beyond acute diarrhoea: Giardia duodenalis, in Cambodia. *Nutrients*. 2018;10(10):1420.

50. Ercumen A, Prottas C, Harris A, Dioguardi A, Dowd G, Guiteras R. Poultry ownership associated with increased risk of child diarrhea: cross-sectional evidence from Uganda. *The American Journal of Tropical Medicine and Hygiene*. 2020;102(3):526.

51. Daniels ME, Shrivastava A, Smith WA, et al. Cryptosporidium and Giardia in Humans, Domestic Animals, and Village Water Sources in Rural India. *Am J Trop Med Hyg*. Sep 2015;93(3):596-600. doi:10.4269/ajtmh.15-0111.

52. Spencer LA, Irwin MT. Cryptosporidium and Giardia prevalence amongst lemurs, humans, domestic animals and black rats in Tsinjoarivo, Madagascar. *Heliyon*. 2020;6(11):e05604.

53. Wolking DJ, Clifford DL, Kelly TR, et al. Boma to banda - a disease sentinel concept for reduction of diarrhoea. *Pastoralism: Research, Policy and Practice*. 2016;6(13).

54. El-Tras WF, Holt HR, Tayel AA, El-Kady NN. Campylobacter infections in children exposed to infected backyard poultry in Egypt. *Epidemiol Infect*. Jan 2015;143(2):308-15. doi:10.1017/S095026881400096X.

55. Odagiri M, Schriewer A, Daniels ME, et al. Human fecal and pathogen exposure pathways in rural Indian villages and the effect of increased latrine coverage. *Water Research*. September 2016;100:232-244. doi:http://dx.doi.org/10.1016/j.watres.2016.05.015

56. Holcomb DA, Knee J, Sumner T, et al. Human fecal contamination of water, soil, and surfaces in households sharing poor-quality sanitation facilities in Maputo, Mozambique. *International journal of hygiene and environmental health*. 2020;226:113496.

57. Schiaffino F, Rengifo Trigoso D, Colston JM, et al. Associations among Household Animal Ownership, Infrastructure, and Hygiene Characteristics with Source Attribution of Household Fecal Contamination in Peri-Urban Communities of Iquitos, Peru. *Am J Trop Med Hyg*. Jan 2021;104(1):372-381. doi:10.4269/ajtmh.20-0810.

58. Boehm AB, Wang D, Ercumen A, et al. Occurrence of Host-Associated Fecal Markers on Child Hands, Household Soil, and Drinking Water in Rural Bangladeshi Households. *Environmental Science & Technology Letters*. 2016;doi:10.1021/acs.estlett.6b00382.

59. Fuhrmeister ER, Ercumen A, Pickering AJ, et al. Effect of sanitation improvements on pathogens and microbial source tracking markers in the rural Bangladeshi household environment. *Environmental science & technology*. 2020;54(7):4316-4326.

60. Huda TMN, Schmidt W-P, Pickering AJ, et al. Effect of Neighborhood Sanitation Coverage on Fecal Contamination of the Household Environment in Rural Bangladesh. *American Journal of Tropical Medicine and Hygiene*. 2019;100(3):717-726.

61. Sprenger LK, Green KT, Molento MB. Geohelminth contamination of public areas and epidemiological risk factors in Curitiba, Brazil. *Revista brasileira de parasitologia veterinária =*

Brazilian journal of veterinary parasitology : Órgão Oficial do Colégio Brasileiro de Parasitologia Veterinária. 2014;23(1):69-73.

62. Bernal RIR, Muñoz O. Factores epidemiológicos relacionados con la seropositividad anti Toxocara canis en niños de pamplona NS, 2015. *CES Salud Pública*. 2017;8(2):3-12.

63. Subrata IM, Suryadhi NT, Mantik-Astawa N, Damriyasa IM. Epidemiological and molecular analysis of Toxplasma Gondii in faecal samples of cats obtained from house of maternal in Bail. *Bali Medical Journal*. 2015;4(2):68-75.

64. de Macedo LO, Santos MAB, de Santana BB, et al. Parasites with zoonotic potential in canine fecal samples from Garanhuns, Pernambuco, Brazil. *Medicina Veterinária (UFRPE)*. 2019;13(2):227-231.

65. Raičević JG, Pavlović IN, Galonja-Coghill TA. Canine intestinal parasites as a potential source of soil contamination in the public areas of Kruševac, Serbia. *The Journal of Infection in Developing Countries*. 2021;15(01):147-154.

66. Medina-Pinto RA, Rodríguez-Vivas RI, Bolio-González ME. Zoonotic intestinal nematodes in dogs from public parks in Yucatán, México. *Biomedica*. 2018;38(1):105-110.

67. Budiono NG, Satrija F, Ridwan Y, Handharyani E, Murtini S. The contribution of domestic animals to the transmission of schistosomiasis japonica in the Lindu Subdistrict of the Central Sulawesi Province, Indonesia. *Veterinary World*. 2019;12(10):1591.

68. Daniels ME, Shrivastava A, Smith WA, et al. Cryptosporidium and giardia in humans, domestic animals, and village water sources in rural India. *American Journal of Tropical Medicine and Hygiene*. 2015;93(3):596-600.

69. Ngure F, Gelli A, Becquey E, et al. Exposure to livestock feces and water quality, sanitation, and hygiene (wash) conditions among caregivers and young children: Formative research in rural Burkina Faso. *The American journal of tropical medicine and hygiene*. 2019;100(4):998.

70. Schriewer A, Odagiri M, Wuertz S, et al. Human and animal fecal contamination of community water sources, stored drinking water and hands in rural India measured with validated microbial source tracking assays. *American Journal of Tropical Medicine and Hygiene*. 2015;93(3):509-516.

71. Wanyiri JW, Kanyi H, Maina S, et al. Cryptosporidiosis in HIV/AIDS Patients in Kenya: Clinical Features, Epidemiology, Molecular Characterization and Antibody Responses. *The American Journal of Tropical Medicine and Hygiene*. 2014;91(2):319-328. doi:10.4269/ajtmh.13-0254.

72. Gboko KD, Traoré SG, Sanhoun AR, et al. Risk factors for the carriage of Streptococcus infantarius subspecies infantarius isolated from African fermented dairy products. *PLoS One*. 2019;14(11):e0225452.

73. Dang-Xuan S, MacDonald LE, Schurer JM, Nguyen-Viet H, Pham-Duc P. Household exposure to livestock and health in the CHILILAB HDSS cohort, Vietnam. *Asia Pacific Journal of Public Health*. 2017;29(5_suppl):72S-83S.

74. Labrique AB, Zaman K, Hossain Z, et al. An Exploratory Case Control Study of Risk Factors for Hepatitis E in Rural Bangladesh. e61351. *PLoS ONE*. May 20133;8(5) doi:http://dx.doi.org/10.1371/journal.pone.0061351

75. Medgyesi DN, Brogan JM, Sewell DK, Creve-Coeur JP, Kwong LH, Baker KK. Where Children Play: Young child exposure to environmental hazards during play in public areas in a transitioning

internally displaced persons community in Haiti. *International Journal of Environmental Research and Public Health*. 2018;15(8):1646.

76. Schmidt WP, Boisson S, Routray P, et al. Exposure to cows is not associated with diarrhoea or impaired child growth in rural Odisha, India: a cohort study. *Epidemiol Infect*. Jan 2016;144(1):53-63. doi:10.1017/S0950268815001090.

77. Collinet-Adler S, Babji S, Sarkar R, et al. Environmental indicators of diarrhea in Vellore, India. *American Journal of Tropical Medicine and Hygiene*. 2011;85(6):175.

78. George CM, Cirhuza LB, Kuhl J, et al. Child mouthing of feces and fomites and animal contact are associated with diarrhea and impaired growth among young children in the Democratic Republic of the Congo: a prospective cohort study (REDUCE Program). *The journal of Pediatrics*. 2021;228:110-116.

79. Parvez SM, Azad R, Pickering AJ, et al. Microbiological contamination of young children's hands in rural Bangladesh: Associations with child age and observed hand cleanliness as proxy. *PLoS One*. 2019;14(9):e0222355.

80. Dorjsuren T, Ganzorig S, Dagvasumberel M, et al. Prevalence and risk factors associated with human cystic echinococcosis in rural areas, Mongolia. *PloS one*. 2020;15(7):e0235399.

81. Verdeja M, Thomas K, Dorsan G, et al. Water, sanitation, and hygiene factors associated with child illness in Tanzania. 2019.

82. Lowenstein C, Vasco K, Sarzosa S, et al. Determinants of childhood zoonotic enteric infections in a semirural community of Quito, Ecuador. *The American journal of tropical medicine and hygiene*. 2020;102(6):1269.

83. Vasco K, Graham JP, Trueba G. Detection of Zoonotic Enteropathogens in Children and Domestic Animals in a Semirural Community in Ecuador. *Appl Environ Microbiol*. Jul 15 2016;82(14):4218-24. doi:10.1128/AEM.00795-16.

84. Delai RR, Freitas AR, Kmetiuk LB, et al. One Health approach on human seroprevalence of anti-Toxocara antibodies, Toxocara spp. eggs in dogs and sand samples between seashore mainland and island areas of southern Brazil. *One health (Amsterdam, Netherlands)*. 2021;13:100353-100353. doi:10.1016/j.onehlt.2021.100353.

85. Cabral Monica T, Evers F, de Souza Lima Nino B, et al. Socioeconomic factors associated with infection by Toxoplasma gondii and Toxocara canis in children. *Transboundary and emerging diseases*. 2022;69(3):1589-1595. doi:10.1111/tbed.14129.

86. Fernando S, Wickramasinghe V, Kapilananda G, Devasurendra R, Amarasooriya J, Dayaratne H. Epidemiological aspects and risk factors of Toxocariasis in a pediatric population in Sri Lanka. 2007.

87. Sazzad HM, Luby SP, Labrique AB, et al. Risk factors associated with blood exposure for sporadic hepatitis E in Dhaka, Bangladesh. *The American journal of tropical medicine and hygiene*. 2017;97(5):1437.

88. Schurer JM, Ramirez V, Kyes P, et al. Long-tailed macaques (Macaca fascicularis) in urban landscapes: gastrointestinal parasitism and barriers for healthy coexistence in northeast Thailand. *The American Journal of Tropical Medicine and Hygiene*. 2019;100(2):357.

89. Gizaw Z, Yalew AW, Bitew BD, Lee J, Bisesi M. Fecal indicator bacteria along multiple environmental exposure pathways (water, food, and soil) and intestinal parasites among children in the rural northwest Ethiopia. *BMC gastroenterology*. 2022;22(1):84-84. doi:10.1186/s12876-022-02174-4.

90. Rivero MR, De Angelo C, Nunez P, et al. Environmental and socio-demographic individual, family and neighborhood factors associated with children intestinal parasitoses at Iguazú, in the subtropical northern border of Argentina. *PLoS neglected tropical diseases*. 2017;11(11):e0006098.

91. Thiem VD, Schmidt WP, Suzuki M, et al. Animal livestock and the risk of hospitalized diarrhoea in children under 5 years in Vietnam. *Tropical Medicine & International Health*. 2012;17(5):613-621.

92. Daniels ME, Smith WA, Schmidt W-P, Clasen T, Jenkins MW. Modeling Cryptosporidium and Giardia in Ground and Surface Water Sources in Rural India: Associations with Latrines, Livestock, Damaged Wells, and Rainfall Patterns. *Environmental Science & Technology*. 2016 Jul;50(14):7498.

93. Conan A, Goutard FL, Sorn S, Vong S. Biosecurity measures for backyard poultry in developing countries: a systematic review. *BMC veterinary research*. 2012;8(1):1-10.

94. Stark H, Omer A, Wereme N'Diaye A, Sapp AC, Moore EV, McKune SL. The Un Oeuf study: Design, methods and baseline data from a cluster randomised controlled trial to increase child egg consumption in Burkina Faso. *Matern Child Nutr*. Jan 2021;17(1):e13069. doi:10.1111/mcn.13069.

95. Clark LA, Watson D. Constructing validity: New developments in creating objective measuring instruments. *Psychological assessment*. 2019;31(12):1412.

96. Polites GL, Roberts N, Thatcher J. Conceptualizing models using multidimensional constructs: a review and guidelines for their use. *European Journal of Information Systems*. 2012;21(1):22-48.

97. Lowe J, Ercumen A, Prottas C, Harris AR. Exploring the determinants and indicators of poultry feces management behaviors in rural Western Uganda. *The Science of the total environment*. 2022;834:155202-155202. doi:10.1016/j.scitotenv.2022.155202.

98. Woldehanna S, Zimicki S. An expanded One Health model: Integrating social science and One Health to inform study of the human-animal interface. *Social Science & Medicine*. 2015/03/01/ 2015;129:87-95. doi:https://doi.org/10.1016/j.socscimed.2014.10.059.

99. Caruso BA, Clasen T, Yount KM, Cooper HL, Hadley C, Haardörfer R. Assessing women's negative sanitation experiences and concerns: The development of a novel sanitation insecurity measure. *International journal of environmental research and public health*. 2017;14(7):755.

100. Hadley C, Wutich A. Experience-based measures of food and water security: biocultural approaches to grounded measures of insecurity. *Human Organization*. 2009;68(4):451-460.

101. Stevenson EGJ, Greene LE, Maes KC, et al. Water insecurity in 3 dimensions: An anthropological perspective on water and women's psychosocial distress in Ethiopia. *Social Science & Medicine*. 2012/07/01/ 2012;75(2):392-400. doi:https://doi.org/10.1016/j.socscimed.2012.03.022.

102. Wolfe WS, Frongillo EA. Building Household Food-security Measurement Tools from the Ground Up. *Food and Nutrition Bulletin*. 2001;22(1):5-12. doi:10.1177/156482650102200102.

103. Cafiero C, Viviani S, Nord M. Food security measurement in a global context: The food insecurity experience scale. *Measurement*. 2018/02/01/ 2018;116:146-152. doi:https://doi.org/10.1016/j.measurement.2017.10.065.

104. Saint Ville A, Po JYT, Sen A, Bui A, Melgar-Quiñonez H. Food security and the Food Insecurity Experience Scale (FIES): ensuring progress by 2030. *Food Security*. 2019/06/01 2019;11(3):483-491. doi:10.1007/s12571-019-00936-9.

105. Stoler J, Miller JD, Adams EA, et al. The Household Water Insecurity Experiences (HWISE) Scale: comparison scores from 27 sites in 22 countries. *Journal of Water, Sanitation and Hygiene for Development*. 2021;11(6):1102-1110. doi:10.2166/washdev.2021.108.

106. Young SL, Boateng GO, Jamaluddine Z, et al. The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. *BMJ Global Health*. 2019;4(5):e001750. doi:10.1136/bmjgh-2019-001750.

107. Diamantopoulos A, Winklhofer HM. Index construction with formative indicators: An alternative to scale development. *Journal of marketing research*. 2001;38(2):269-277.

108. Hardin AM, Chang JC-J, Fuller MA, Torkzadeh G. Formative measurement and academic research: In search of measurement theory. *Educational and Psychological Measurement*. 2011;71(2):281-305.

109. Roberts N, Thatcher J. Conceptualizing and testing formative constructs: Tutorial and annotated example. *ACM sigmis database: The database for Advances in Information Systems*. 2009;40(3):9-39.

Chapter 4. Research Aim 3: The development and validation of a survey to measure fecal-oral child exposure to zoonotic enteropathogens: The FECEZ Enteropathogens index[3]

4.1. Abstract

Exposure to animal feces is a significant transmission route of enteric pathogens among children in low- and middle-income countries. However, there are currently no validated or standardized approaches to measure exposure. Standard metrics are needed to enable comparisons of child exposure to zoonotic enteric pathogens within and across communities, and to evaluate the effectiveness of interventions. We developed and validated a measure for fecal-oral child exposure to zoonotic enteropathogens, the FECEZ Enteropathogens index. We operationalized child exposure as the combination of two content domains, child environmental characteristics and child behaviors. With cross-sectional data from 297 mothers in northwestern coastal Ecuador, we carried out principal component analysis to reduce a 105-item pool and to determine the optimal number of components. The final, two-domain index consists of seven interpretable components and 34 items. Only two children had no exposure (i.e., exposure scores of 0). Those residing in households that owned animals had significantly higher sub-domain and overall exposure scores compared to those in households that did not own animals. Children in rural communities had significantly higher sub-domain and overall index exposure scores compared to urban-residing children. This measure is the first major step to improve upon and standardize measurement of child exposure to zoonotic enteropathogens. It can also be used to develop and measure the effectiveness of interventions that aim to reduce child exposure, and to determine if agriculture and development programming focused on animal husbandry have unintended consequences for child health.

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4.2. Introduction

Enteric pathogens pose serious health risks for children under age five. Persistent exposure and recurrent enteric infections are associated with diarrhea (the fifth leading cause of death in children under five), environmental enteric dysfunction, and deficits in growth and cognitive development.[1-4] Enteric infections and sequelae disproportionately affect children living in low- and middle-income countries (LMICs) due to inequitable access to healthcare, inadequate water, sanitation, and hygiene, and widespread fecal contamination of the environment.[2,5-15]

Exposure to animal feces is an important transmission route of enteric pathogens,[16-20] particularly among children in LMICs where animals are ubiquitous and insufficient separation of animal feces from domestic spaces is well documented.[20-26] Many pathogens capable of infecting humans are transmissible via animal feces,[16] some of which contribute significantly to the global burden of diarrheal disease. Four pathogens that can be transmitted in animal feces (*Campylobacter* spp., *Cryptosporidium* spp., enteropathogenic *E. coli*, non-typhoidal *Salmonella* (NTS)) are responsible for 28.3% of the estimated global diarrhea deaths in children under five years, though the specific attributable fraction of animal-sourced infections is unquantified.[16] Global animal feces production greatly exceeds feces produced by humans. Livestock animal feces accounts for 80% of the global fecal load, most of which is feces at the household level.[27]

Significant challenges remain in understanding the scope of child exposure to zoonotic enteric pathogens and areas of highest risk in need of intervention. Such challenges are in part due to current approaches to the measurement of exposure, which are diverse and overwhelmingly distal from exposure itself.[28] There are currently no validated or standardized approaches to measure exposure, and researchers assess exposure inconsistently with varied methods and measures for many types of animals.[28] Inconsistent and varied approaches make it difficult to compare findings across studies and settings and to determine whether diarrhea and other health outcomes are associated with the degree of exposure or with the number and type of factors measured in a specific study. Additionally, while most existing measures

capture a single attribute of exposure (e.g., animal ownership, presence of animal feces),[28] it has not yet been clearly demonstrated whether one particular factor, more than others, can cause adverse child health outcomes, or whether a single factor exerts an effect independent of other factors. Creation and validation of a standard, multidimensional measure to capture child exposure to zoonotic enteric pathogens is needed to enable and expand researchers' and practitioners' ability to comprehensively assess exposure, evaluate the issue within and across communities, and develop and evaluate interventions.

This study improves upon existing measures of fecal-oral child exposure to zoonotic enteropathogens by using a sequential mixed methods approach to develop and validate a survey-based measure, i.e., the FECEZ Enteropathogens index. To generate potential measure items, we leveraged qualitative data from urban and rural Ecuadorian communities and existing exposure measures identified through a systematic review, both of which increase the generalizability of the index. We collected survey data from the same Ecuadorian communities to create and evaluate the measure, identifying a set of items that can be applied in other settings to quantify the degree to which children are exposed. The validated index can standardize measurement of child exposure to zoonotic enteropathogens across studies and settings, and be used to develop and measure the effectiveness of interventions that aim to reduce exposure.

4.3. Methods

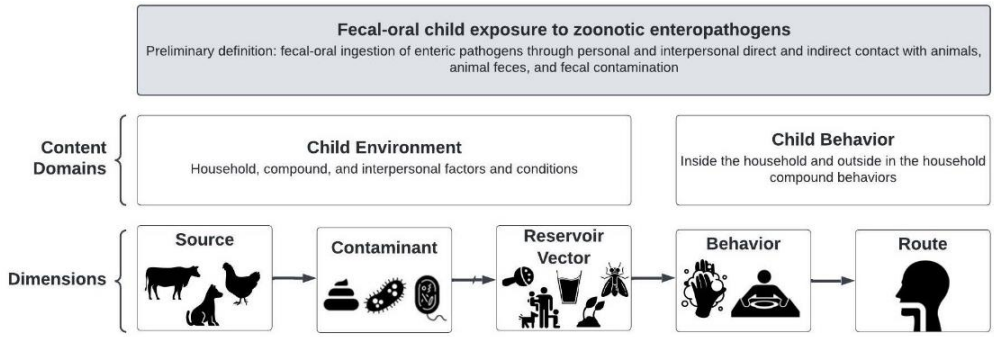
Defining and conceptualizing child exposure to zoonotic enteric pathogens

Following measurement development established practices,[29-31] we offer a preliminary definition of 'child exposure to zoonotic enteric pathogens': fecal-oral ingestion of enteric pathogens through personal and interpersonal direct and indirect contact with animals, animal feces, and fecal contamination. We provide an intentionally broad conceptual definition to be iterated upon over time.[32-34]

We developed a framework (Figure 4.1) adapted from the exposure science source-to-outcome continuum[35] as well as our qualitative and systematic review research (details provided below), that is the conceptual basis of the FECEZ Enteropathogens index. The exposure science continuum – which includes

source, contaminant, reservoir or vector, behavior, route, and outcome – delineates the specific elements of exposure, elucidating what is critical to assess to improve the precision of measurement approaches. Our framework considers exposure to be constituted by two distinct content domains. We define the environment domain as the child's household, compound, and interpersonal environment, and focuses on sources of zoonotic enteric pathogens (i.e., animals), the contaminant itself (i.e., enteric pathogens in animal feces), and pathogen reservoirs and vectors (e.g., soil, other people). The behavior domain includes child behaviors inside the home and outside the home in the household compound, and focuses on interactions with potential sources, contaminants, reservoirs, and vectors that could lead to fecal-oral ingestion of zoonotic enteric pathogens.

Figure 4.1. Conceptual framework, including content domains and dimensions*, of fecal-oral child exposure to zoonotic enteropathogens



*Content domains are critical attributes of the concept being measured (i.e., fecal-oral child exposure to zoonotic enteropathogens) and are derived from the concept analysis phase during measurement development. Dimensions are the range of characteristics or elements that constitute the concept and its domains.

Setting

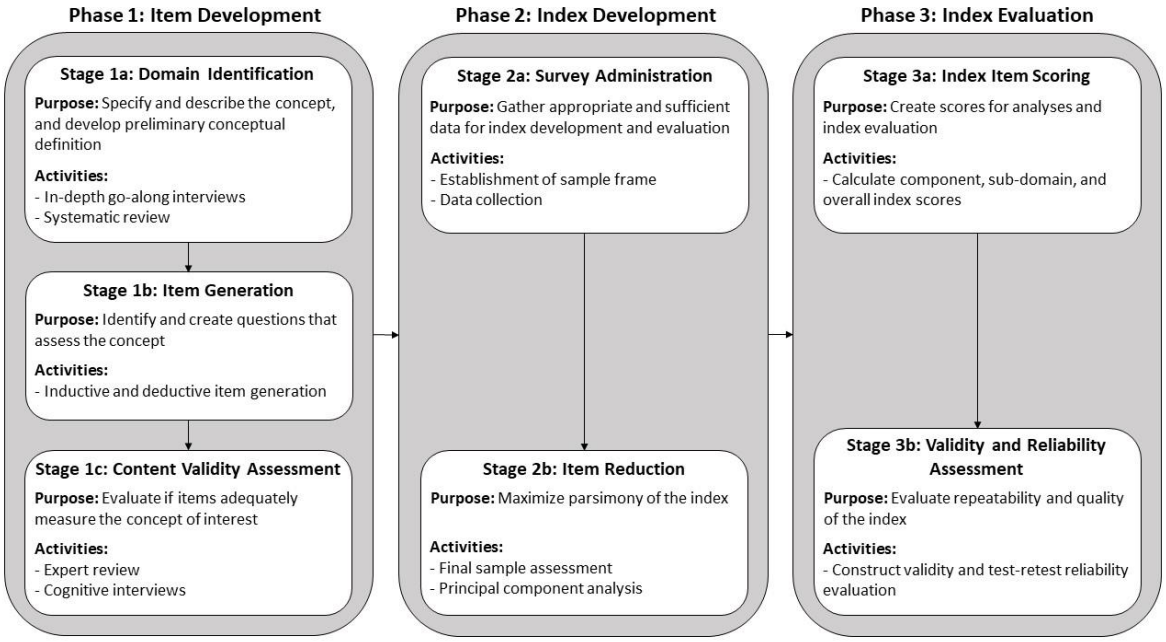
We conducted research in multiple, diverse communities in northwestern coastal Ecuador in conjunction with an ongoing birth cohort study, Enteropatógenos, Crecimiento, Microbioma, y Diarrea (referred to as ECoMiD).[36] Data were collected in four ECoMiD study sites engaged in a birth cohort study to assess the impact of environmental exposures on enteric pathogen infections, gut microbiome composition, and development during the first two years of children's lives. The study area is largely populated by Afro-Ecuadorians and mestizos; some indigenous individuals (i.e., Chachi's) live in the region as well. Study sites included: (1) Esmeraldas, the urban hub of the study area; (2) Borbón, a semi-rural town in Esmeraldas Province; (3) rural villages near Borbón that are accessible by road; and (4) rural villages near

Borbón that are accessible by boat. Esmeraldas (population: 160,000[37]) is a densely populated city and the capital of Esmeraldas Province. The city has the most access to water, sanitation, and infrastructure.[38] Borbón (population: 7,700[37]), a town in the Esmeraldas Province, is located at the convergence of the Cayapas, Santiago, and Onzole rivers. The town has inadequate infrastructure for its size, including minimal water and sanitation infrastructure (e.g., untreated sewage, basic solid waste management). Approximately 125 small villages (population: 50-500 per village[37]) lie along the three rivers, some of which have access to Borbón via road (i.e., rural road communities) and largely lack infrastructure, though some have been recently connected to drinking water systems.[38,39] Other villages are only accessible by river (i.e., rural river communities) and are comparatively more remote and lack centralized infrastructure.

Overview of research design

We used a sequential mixed methods approach[40] to create and evaluate the index, following measure development best practices.[29-31] An overview of the three-phase approach is depicted in Figure 4.2 and subsequently detailed.

Figure 4.2. Schematic of sequential mixed methods research design to create and evaluate a child exposure to zoonotic enteric pathogens index



Phase 1: Item Development

To identify content domains and generate potential index items, we conducted and analyzed data from in-depth interviews (IDIs) and a systematic review. We finalized and evaluated the proposed items adequacy (i.e., content validity) through expert review and cognitive interviews with individuals similar to our target population.[29,30]

Phase 1 Stage 1a: Domain Identification

In-depth go-along interviews

To identify critical attributes (i.e., content domains) and the range of characteristics (i.e., dimensions) that constitute fecal-oral child exposure to zoonotic enteropathogens, we conducted 58 go-along, semi-structured IDIs with mothers of children 6-18 months of age enrolled in the on-going birth cohort study. Go-along IDIs combine interviewing and participant observation, allowing the participant to actively engage with and discuss the spaces being discussed.[41,42] We used purposive quota sampling to interview equal proportions of participants who did (n=32) and did not (n=26) own animals to ensure accurate representation of each study site and enable comparison of exposure variation. Interviews queried conditions and maternal and child behaviors that could lead to child exposure to zoonotic pathogens, capturing details related to animals, environmental conditions, and behaviors on a typical day. To provide additional context about animals and environmental conditions, we conducted 29 interviews with individuals from the same communities who were not part of the cohort study and owned, cared for, and/or worked with various animals. Non-cohort IDIs queried how animals are cared for (e.g., feeding, animal feces management) and by whom, and decision-making about animal ownership and management. IDIs were conducted by co-author BCA, a qualitative researcher with more than 10 years of research experiences who grew up and lives in the study area. Additional information about the qualitative methods, analyses, and findings are reported elsewhere (see Chapter 2).

Systematic review

To identify additional exposure attributes and characteristics, we conducted a systematic review to audit existing measures of human exposure to animal feces in LMICs. We identified 1,428 quantitative measures that informed item identification, and increases the generalizability of the measure to other settings. Detailed information about the review can be found elsewhere.[28]

Phase 1 Stage 1b: Item Generation

To generate potential items for the measure, we leveraged data from IDIs (inductive approach) and the systematic review (deductive approach). We analyzed IDIs to understand the scope of child interaction with animals and animal feces and potential exposure to zoonotic enteric pathogens. We reviewed transcript segments from relevant codes and held debriefing meetings to conceptualize the constituents of exposure and recorded the prominence or frequency at which each constituent occurred in the sample. We identified two content domains of exposure based on analyses: the child's environment and the child's behaviors inside the home and outside home in the household compound. We created an initial list of items for each domain based on the scope and frequency of factors in our data. As a final step, we reviewed concepts and measures captured via the systematic review to identify additional relevant domains and items.

Phase 1 Stage 1c: Content Validity Assessment

Expert review

To evaluate if proposed items adequately measure the construct (i.e., child exposure to zoonotic enteric pathogens), we conducted three rounds of expert review. First, four co-authors (BAC, MCF, RH, KL) were sent draft items to assess the extent to which questions reflected the construct of interest and were appropriately worded, ordered, representative, and comprehensive. Second, we conducted a formalized expert review process with two other co-authors (JNSE, GOL) and two external experts who were asked to evaluate each item on a scale of 1-4 for representativeness and clarity and provide comments on representativeness, clarity, and comprehensiveness. Scores and comments for each item were then used to

identify items that needed to be edited, deleted, or added. Third, we translated items from English to Spanish and the co-author who conducted IDIs for this study reviewed and commented on items.

Cognitive interviews

As a final assessment of content validity, co-author BCA conducted 20 cognitive interviews with mothers in the study area who were not enrolled in ECoMiD. The researcher went through each item and asked participants to explain the question in their own words and how they determined their responses to questions to evaluate the suitability of questions for the target population and if responses produce valid measurements. Edits to the tool were made based on cognitive interview findings and debriefing meetings between co-authors AMB and BCA.

Phase 2: Index Development

To collect data for index development and evaluation, we administered the revised items within a broader survey. Then, to reduce the number of items and maximize parsimony, we conducted PCA.

Phase 2 Stage 2a: Survey Administration

Sampling frame

To obtain data suitable for index development, we collected cross-sectional data from a sample of 200-300 participants, which has been shown to be adequate for performing component analysis, though no consensus for optimal sample size exists.[29,43-45] Participant recruitment followed a simple sampling strategy using a random-walk method in the same neighborhoods where IDIs were conducted and where the ECoMiD study participants reside. An enumerator walked through neighborhoods and knocked on doors to screen participants for eligibility, skipping households with mothers and children enrolled in the ECoMiD study. To be eligible, aged 18 or older, a mother to a child six months to five years old, and not a member of the ECoMiD cohort study. ECoMiD cohort members were excluded to avoid research fatigue given their ongoing participation in various cohort activities. If an eligible individual consented to participate, the enumerator would administer the survey or make an appointment to return.

Data collection

To collect data for index development and evaluation, we administered a 30-minute survey that included measure items, modules on mother and child demographics, maternal perception and knowledge about exposure to animals and animal feces, water and sanitation access, child health, and household characteristics. There were 52 items designed to measure the two exposure sub-domains, which asked mothers how often a particular event or behavior occurred in the last week: never, rarely, sometimes, frequently (see Appendix 6.2 Table S4 for full list of items). Measure items were ordered in the survey to build in intensity or proximity to exposure. For example, environmental items were asked first and items about child contact with animals and their feces were asked last. Items that assessed the child's household and compound environment were about animals and animal feces with potential follow-up items based on responses, meaning mothers were asked a range of 52-105 questions (85 environment items and 20 behavior items). Participants received an assortment of household items, such as soap and toothpaste, as compensation for their time.

To facilitate the assessment of test-retest reliability (i.e., how consistent index scores are across time), we re-administered the survey sections with measure items to approximately 25% of participants.[29,30] Repeat surveys took approximately 15 minutes to complete and were conducted among a random sample of those who agreed to a second visit within a three-to-seven-day window. Re-administration occurred within this timeframe because the items refer to 'the past week' and we wanted to capture responses within an overlapping period to reduce the likelihood of meaningful events or changes that would lead to different responses to survey items.

One enumerator was recruited to administer all surveys in Spanish with Open Data Kit (ODK) using an electronic tablet. The enumerator completed one week of training conducted by co-author AMB about the purpose of the survey, interview techniques, research ethics, and logistics. Interactive practice of the consent and survey administration processes was conducted during training before data collection began. Survey data collection occurred in August-September 2022.

Phase 2 Stage 2b: Item Reduction

Final sample assessment

To reduce the number of initial items and assess the availability of complete cases for the development of the two sub-domain indices, we examined the frequencies of responses for each set of items and assessed missingness. Items with limited theoretical applicability to the construct where few respondents (<5%) reported a certain condition or behavior were removed prior to PCA. No variables were missing responses. We also conducted pairwise correlation tests for items in each sub-domain, separately. Items with p >0.90 were consolidated prior to PCA to reduce the number of initial items to a smaller subset of non-highly correlated items where logic and theory supported items interrelatedness.

To evaluate if each set of items were suitable for PCA, we conducted three statistical tests. First, Kaiser-Meyer-Olkin Measure of Sampling Adequacy[46] was used to determine the proportion of variance in variables that may be caused by underlying factors. We considered values above 0.50 overall and per item as adequate in demonstrating that PCA was useful to reduce the dimensionality of our data. Second, Bartlett's Test of Sphericity[47] was used to test if the correlation matrix was an identity matrix, meaning variables are unrelated and therefore not suitable for PCA. We considered p-values less than 0.05 an indication that the correlation matrix was not an identity matrix. Lastly, we calculated the determinant of the correlation matrix to asses if multicollinearity or singularity were issues in our data. We considered determinant values >0.00001 to indicate no issues.

Principal component analysis

To determine the optimal number of components that fit each sub-domain, we conducted categorical PCA with multivariate analysis with optimal scaling using the *princals* function from the *Gifi* package[48] in R Studio version 4.0.5[49] on the raw ordinal data for the two sets of items separately. We used a linearly scaled fit (i.e., linear knots with no interior knots) to transform the ordinal values to be linearly scaled with equal distances between points, which aligns with the meaning behind the ordinal data (i.e., the number of days). To identify the number of principal components (PCs) to retain, we considered

eigenvalues, a scree plot, and in part, theory based on our conceptualization of exposure. We used Kaiser's Criteria (eigenvalues >1.0) and a scree plot to determine the 'elbow' point, which demarks where the eigenvalues go from exponential decay to a linear trend.[30,50,51] To decide on final solutions, we used an iterative process. We re-ran analyses to examine solutions with a varying number of components, balancing interpretability and the percent of variance explained to produce parsimonious, functional, and interpretable indices.[29,30,52] We also assessed item loadings and theoretical fit of each item within components to determine if an item should be dropped. We decided *a priori* to conduct stepwise removal of items with loadings <0.40 and/or that were loaded on several components and did not theoretically make sense.[30,51] After each item was removed, pre-analysis statistical tests and eigenvalues were assessed to make sure our data were still suitable for PCA and that we were still assessing an appropriate number of components. The final component structures were assessed using knowledge of child exposure to zoonotic enteric pathogens to ensure that items and components were appropriate and relevant.

Phase 3: Index Evaluation

To create and evaluate the FECEZ Enteropathogens index, we calculated scores based on PCA results and assessed scores construct validity and test-retest reliability in R studio version 4.0.5.[49]

Phase 3 Stage 3a: Index Item Scoring

To calculate PC scores, we used an unweighted approach and calculated the sum of responses for each final item using the original, ordinal values (i.e., 0 = never, 1 = rarely, 2 = sometimes, 3 = frequently).[29,30] We calculated each components' score by summing an individual's ordinal values together for items that loaded to each component in the final PCA solutions. If items were cross-loaded, the item was considered part of the component where the loadings were the largest.

To create index scores for substantive analysis, PC scores were used to calculate sub-domain (or sub-index) and overall index scores. We used summations of ordinal data to calculate index scores, as opposed to transformed scores from component loadings, in order to facilitate interpretability and index

score comparisons in future research given that loadings will differ by study population. Higher scores indicate a greater frequency of occurrence.

Phase 3 Stage 3b: Construct Validity and Test-retest Reliability Assessment

To evaluate if the index accurately assesses what it was designed for (i.e., construct validity), we conducted bivariate linear regression analyses to examine if the measure behaves as expected in relation to "known groups."[29,30] Specifically, we assessed whether scores for each component, sub-domain, and the overall index were significantly different by community type (i.e., urban, semi-rural, rural road, rural river), hypothesizing that there would be detectable differences in exposure levels across the urban-rural gradient because the number and diversity of animals varies across the sites. We also investigated whether scores were significantly different by household animal ownership, as existing literature suggest that exposure may be higher among children in households with animals.

To determine if the index provided a stable measure that can be used on repeat occasions (i.e., test-retest reliability),[29,30] we calculated intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals using the *ICC* function from the *psych* package[53] in R studio version 4.0.5[49] based on a single-rating, absolute agreement, two-way mixed effects model.[54] ICCs were calculated for each PC, the environment and behavior sub-indices, and the overall index for participants who were surveyed twice. We used the following guidelines to evaluate ICC values: <0.50 poor reliability, 0.50-0.75 moderate reliability, 0.76-0.90 good reliability, and >0.90 excellent reliability.[54]

Ethics

Emory University (IRB # 00101202) and Universidad San Francisco de Quito Institutional (IRB # 2018-022M and 021-011M) Review Boards approved all study activities. Participants provided written consent prior to data collection.

4.4. Results

Participant Demographics

In total, we administered 297 surveys across the four study sites. Most households owned at least one type of animal (55.6%, *n*=165), with dogs and cats being the most common (Table 4.1). A quarter (*n*=75) of children were reported by mothers to have had a fever in the week prior, 13.5% (*n*=40) had diarrhea, and 7.7% (*n*=23) had vomited. Sex-disaggregated demographic characteristics are provided in Table S5 (Appendix 6.2).

Table 4.1. Maternal, child, and household characteristics for total sample and by the four study sites (*n*=297)

Characteristics	**Total**		**Rural river**		**River road**		**Semi-rural**		**Urban**	
	n		*n*		*n*		*n*		*n*	
Number of participants	297		46	15.4%	76	25.6%	98	33.0%	77	25.9%
Maternal characteristics										
Age (mean [std] in years)	29	(8.0)	28	(7.0)	30	(9.0)	28	(7.0)	32	(8.0)
Ethnicity										
Afro-Ecuadorian	221	74.4%	42	91.3%	64	84.2%	67	68.4%	48	62.4%
Mestizo	70	23.6%	4	8.7%	12	15.8%	26	26.5%	28	36.4%
Indigenous - Chachi	2	0.7%	0	0.0%	0	0.0%	2	2.0%	0	0.0%
Other	4	1.3%	0	0.0%	0	0.0%	3	3.1%	1	1.3%
Education (mean [std] in years)	11.5	(3.5)	9	(4.0)	11	(3.5)	12	(3.0)	13	(3.0)
Child characteristics										
Age (mean [std] in months)	33	(15.5)	34	(16.0)	36	(15.0)	34	(15.0)	29	(16.0)
Sex- female	153	51.5%	25	54.3%	44	57.9%	48	49.0%	36	46.8%
Currently breastfed	34	11.4%	3	6.5%	4	5.3%	9	9.2%	18	23.4%
Symptoms in last 7 days										
Diarrhea	40	13.5%	11	23.9%	11	14.5%	14	14.3%	4	5.2%
Fever	75	25.3%	19	41.3%	30	39.5%	19	19.4%	7	9.1%
Vomit	23	7.7%	3	6.5%	8	10.5%	10	10.2%	2	2.6%
Blood in stool	1	0.3%	0	0.0%	0	0.0%	1	1.0%	0	0.0%
Household characteristics										
Number of people* (mean [std])	5	(2.5)	6	(2.0)	5	(2.0)	5	(3.0)	5	(3.0)
Owns animal(s)	165	55.6%	22	47.8%	48	63.2%	61	62.2%	34	44.2%
Dogs	115	38.7%	13	28.3%	29	38.2%	44	44.9%	29	37.7%
Cats	62	20.9%	8	17.4%	20	26.3%	22	22.4%	12	15.6%
Free-range chickens	35	11.8%	4	8.7%	14	18.4%	15	15.3%	2	2.6%
Ducks	3	1.0%	0	0.0%	3	3.9%	0	0.0%	0	0.0%
Dairy cattle	2	0.7%	0	0.0%	0	0.0%	2	2.0%	0	0.0%
Horses	1	0.3%	0	0.0%	1	1.3%	0	0.0%	0	0.0%
Pigs	12	4.0%	2	4.3%	5	6.6%	5	5.1%	0	0.0%
Rabbits	7	2.4%	0	0.0%	5	6.6%	2	2.0%	0	0.0%
Source of drinking water										
Piped	54	18.2%	0	0.0%	24	31.6%	10	10.2%	20	26.0%
Bottled/purchased	170	57.2%	5	10.9%	42	55.3%	82	83.7%	41	53.2%
Protected well	9	3.0%	0	0.0%	6	7.9%	3	3.1%	0	0.0%
Rain water	43	14.5%	41	89.1%	2	2.6%	0	0.0%	0	0.0%
Unprotected well	1	0.3%	0	0.0%	1	1.3%	0	0.0%	0	0.0%
River water	4	1.3%	0	0.0%	1	1.3%	3	3.1%	0	0.0%

Tanker-truck	16	5.4%	0	0.0%	0	0.0%	0	0.0%	16	20.8%
Treat drinking water	88	29.6%	19	41.3%	22	28.9%	21	21.4%	26	33.8%
Source(s) of water for child+										
Piped	108	36.4%	0	0.0%	31	40.8%	45	45.9%	32	41.6%
Bottled/purchased	81	27.3%	0	0.0%	23	30.3%	45	45.9%	13	16.9%
Protected well	26	8.8%	1	2.2%	16	21.1%	9	9.2%	0	0.0%
Rain water	49	16.5%	41	89.1%	4	5.3%	4	4.1%	0	0.0%
River water	11	3.7%	4	8.7%	4	5.3%	3	3.1%	0	0.0%
Tanker-truck	32	10.8%	0	0.0%	0	0.0%	0	0.0%	32	41.6%
Treat water for child	114	38.4%	22	47.8%	29	38.2%	29	29.6%	34	44.2%

*n=292, Five observations have missing values

+Participants could report more than one source of water for their child so totals may add to more than 100%

Sub-Domain and Overall Index Development

Final Sample Assessment

The survey included 105 items for potential inclusion in the final measures: 85 environment items and 20 behavior items. All participants responded "never" to 37 environment items and one behavior item, so they were eliminated due to their irrelevancy to this population. We eliminated 21 additional environment items because they were near zero variance predictors and had limited relevance for the sample. Lastly, four behavior items were consolidated into two items because they were highly correlated and theoretically similar. For example, items that captured children putting soil and sand in their mouths were consolidated into a single item (p >0.94). PCA was therefore conducted with 27 environment items and 17 behavior items to create two sub-indices. Distributions of item responses are in Table S6 (Appendix 6.2). Items that were omitted and reasons for omission are in Table S4 (Appendix 6.2).

Principal Component Analysis

Pre-analysis tests indicated that remaining data for each sub-domain were suitable for PCA. For the environment and behavior items, the Kaiser-Meyer-Olkin measure values were 0.71 and 0.75, respectively, indicating acceptable sampling adequacy. The Bartlett's Test of Sphericity revealed that the between-item correlations were sufficient for PCA for both sets of items (environment items: K-squared = 2094.8, degrees of freedom (df) = 19, p-value <0.001; behavior items: K-square = 2079.4, df = 13, p-value <0.001). There were also no issues with multicollinearity or singularity; determinants of the correlation matrices were 0.002 and 0.01 for the environment and behavior items, respectively.

Child environment sub-domain

For the environment sub-domain, we determined that a five-component solution best suited the data theoretically, based on a screeplot, Kaiser's Rule (eigenvalues >1.0), and the amount of variance explained by PCs. Seven additional environmental items were omitted during analyses due to loadings <0.40 and/or cross-loading that was not interpretable (Appendix 6.2 Table S4). The final environment sub-index included 20 items and explained 57% of the variance (Table 4.2). The fit appeared to be good with a loss value of 0.89 and a solution obtained with 43 iterations.

Table 4.2. Eigen values, explained variance, cumulative explained variance, and component loadings for child environment sub-domain PCA solution

Solution characteristics	**PC1***	**PC2**	**PC3**	**PC4**	**PC5**
Eigen value	3.76	2.35	2.21	1.73	1.26
Variance explained by PC	0.19	0.12	0.11	0.09	0.06
Cumulative variance explained	0.19	0.31	0.42	0.51	0.57
Solution items					
Mother personally feeds or gives water to an animal	**-0.79**	-0.08	-0.13	-0.02	-0.03
Mother personally cleans the habitat or place where an animal sleeps and/or defecates	**-0.75**	0.09	-0.26	0.02	-0.19
Mother personally bathes, cleans, or grooms an animal	**-0.71**	0.12	-0.33	-0.00	-0.05
Mother personally touches or play with an animal	**-0.70**	0.07	-0.30	0.00	0.03
Mother personally eliminates or cleans the poop of an animal	**-0.70**	-0.12	-0.29	0.15	-0.24
Dogs enter the house	**-0.53**	0.30	-0.03	-0.28	0.32
Free-range chickens spend time outside near the house	-0.27	**-0.77**	0.12	-0.06	0.00
Free-range chickens enter the house	-0.12	**-0.72**	0.05	-0.05	-0.01
Free-range chicken poop outside the house near or in the yard	-0.24	**-0.70**	0.20	0.11	0.03
Free-range chicken poop inside the house	-0.10	**-0.56**	0.11	0.15	0.02
Cats enter the house	-0.37	0.22	**0.76**	0.23	0.02
Cats spend time outside near the house	-0.25	0.22	**0.64**	0.29	-0.13
Cats sleep inside the house	**-0.40**	0.21	**0.60**	0.16	0.11
Cat poop outside the house near or in the yard	-0.15	-0.05	**0.40**	0.30	-0.26
Dairy cattle spend time outside near the house	-0.10	-0.11	0.26	**-0.70**	-0.05
Dairy cattle poop outside the house near or in the yard	-0.00	-0.02	0.25	**-0.70**	-0.08
Household member apart from mother and child under 5 years works or cares for an animal	-0.16	-0.08	0.37	**-0.52**	0.00
Dogs sleep inside the house	**-0.44**	0.23	0.06	-0.12	**0.58**
Dog poop outside the house near or in the yard	-0.17	0.24	0.07	-0.22	**-0.57**
Dogs spend time outside near the house	0.04	0.17	-0.01	-0.13	**-0.53**

*PC = Principal component; bold numeric values indicate item loading to the specific PC

The environment sub-domain PCA yielded strong loadings onto five interpretable components, each listed with the proportion of variance accounted for: maternal factors (19%), free-range chicken factors (12%), cat factors (11%), dairy cattle factors (9%), and dog factors (6%) (Table 4.2). The PCs broadly corresponded to our two initially hypothesized environment-related dimensions: the child's household and compound environment and the child's interpersonal environment. Specifically, PCs 2-5 included items related to specific species of animals and their feces. The item about other household members working with or caring for animals loaded on PC4 with dairy cattle items, which could represent farming communities/households where dairy cattle are present and family's own, work with, and/or care for them. PC1 included items about maternal behaviors and interactions with animals and their feces. The items about dogs entering and dogs and cats sleeping in the household also loaded on this component, which likely indicates that mothers interact with dogs and cats and their feces that enter or sleep inside their house. Dogs entering the household loaded to PC1 (maternal factors) and not to PC5 (dog factors), which could be indicative of dogs specifically entering houses to be fed, bathed, groomed, or played with and contributing to interpersonal environmental contamination.

Child behavior sub-domain

For the behavior sub-domain, a two-component solution best suited the data. Three additional items were omitted during analyses due to loadings <0.40 and/or cross-loading (Appendix 6.2 Table S4). The final behavior sub-index included 14 items, explaining 42% of the variance (Table 4.3). The fit appeared adequate with a loss value of 0.79 and a solution obtained with 12 iterations.

Table 4.3. Eigen values, explained variance, cumulative explained variance, and component loadings for child behavior sub-domain PCA solution

Solution characteristics	**PC1***	**PC2**
Eigen value	3.34	2.52
Variance explained by PC	0.24	0.18
Cumulative variance explained	0.24	0.42
Solution items		
Child puts objects or toys that had contact with the dirt outside your house in their mouth	**0.73**	-0.25
Child plays outside the house without shoes on	**0.67**	0.13

Child puts dirt, soil, or sand in their mouth	**0.59**	-0.28
Child plays in dirt, soil, or sand outside the house	**0.59**	0.05
Child puts objects or toys that had contact with the floor inside your house in their mouth	**0.58**	-0.20
Child plays outside the house in an area where an animal lives or sleeps	**0.56**	0.12
Child puts shoes in their mouth	**0.53**	-0.32
Child plays with or carries around shoes like a toy	**0.52**	0.02
Child touches or plays with an animal	**0.45**	0.34
Child cleans or helps others clean the habitat or place where an animal sleeps and/or defecates	0.16	**0.76**
Child bathes, cleans, or grooms or helps others bathe, clean, or groom an animal	0.22	**0.75**
Child feeds or gives water or helps others feed or give water to an animal	0.29	**0.67**
Child cares for or helps others care for an animal that was sick	0.02	**0.56**
Child touches, removes, or cleans animal poop	0.11	**0.54**

*PC = Principal component; bold numeric values indicate item loading to the specific PC

The behavior sub-domain PCA yielded strong loadings onto two interpretable components, each listed with the proportion of variance accounted for: play and mouthing behaviors (24%), and animal caregiving and feces management behaviors (18%) (Table 4.3). The components broadly corresponded to our structuring of questions that build in proximity to exposure to animals and their feces. Specifically, PC1 is comparatively more distal from exposure, including items about child play in potentially risky environments and mouthing potentially contaminated objects. PC2 includes items of increasing proximity to exposure, specifically caring for or helping others care for animals and interacting with animal feces.

Index Evaluation

Index Item Scoring

The mean overall FECEZ Enteropathogens index score was 27.21 (standard deviation [SD]: 12.75) out of 102 (Table 4.4). The average environment sub-domain and behavior sub-domain scores were 14.63 (SD: 8.57) out of 60 and 12.57 (SD: 7.10) out of 42, respectively. Environment and behavior sub-domain scores were moderately positively associated, $r(295) = 0.31$, $p < 0.01$ (Appendix 6.2 Figure S2). Histograms for sub-domain and overall index scores are provided in Figures S3-S5 (Appendix 6.2). On average, scores were highest among children living in the rural river study site (Table 4.5). Children in the urban study site had the lowest average scores except for environment PC5 (dog factors), signifying less

child interaction with animals and their environment and less presence of animals and their feces, apart from dogs.

Table 4.4. Means and standard deviations of scores for Principal Components (PCs), child environment and behavior sub-domains, and the overall FECEZ Enteropathogens index (n=297)

	No. of items	**Possible Score range**	**Mean score (std)**
Total	34	0-102	27.21 (12.75)
Child environment sub-total	20	0-60	14.63 (8.57)
PC1: Maternal factors	6	0-18	5.42 (5.64)
PC2: Free-range chicken factors	4	0-12	1.48 (2.67)
PC3: Cat factors	4	0-12	2.92 (3.35)
PC4: Dairy cattle factors	3	0-9	0.30 (0.96)
PC5: Dog factors	3	0-9	4.52 (1.98)
Child Behavior sub-total	14	0-42	12.57 (7.10)
PC1: Play and mouthing behaviors	9	0-27	11.99 (6.55)
PC2: Animal caregiving and feces behaviors	5	0-15	0.58 (1.72)

Validity and Reliability Assessment

The PC, sub-domain, and total index scores differed significantly by community type (Table 4.5), indicating good construct validity (i.e., known-groups validity). As hypothesized, there was a statistically significant difference between scores across community type/study site. Children in rural river, rural road, and semi-rural communities had significantly higher environment sub-domain, behavior sub-domain, and total index exposure scores compared to urban-residing children. There were also significant differences across PCs, though these differences varied by component as expected. For example, children in rural river, rural road, and semi-rural communities had significantly higher scores related to free-range chickens (i.e., environment PC2) compared to urban-residing children, which was expected given the sparseness of free-range chickens in the urban study site. However, only children in the semi-rural study site had significantly higher scores related to dogs (i.e., environment PC5), indicative of the presence of dogs and their feces across all study sites.

Table 4.5. Component, sub-domain, and overall FECEZ Enteropathogens index scores by community type and animal ownership, and intraclass correlation coefficient [ICC] estimates

	ICC estimates	**Mean score (sd) by community type**				**Mean score (sd) by animal ownership**		
	Kappa (95% CI)	**Urban** (*n*=77, *ref.*)	**Semi-rural** (*n*=98)	**Rural road** (*n*=76)	**Rural river** (*n*=46)	**None** (*n*=132, *ref.*)	**1 type** (*n*=110)	**>1 type** (*n*=55)
Total	0.81 (0.70, 0.88)	18.10 (11.55)	**29.07 (11.45)**	**29.82 (11.12)**	**34.15 (12.05)**	20.52 (11.16)	**30.05 (10.63)**	**37.55 (11.25)**
Child environment sub-domain	0.79 (0.68, 0.86)	10.32 (8.19)	**15.82 (8.66)**	**16.28 (8.13)**	**16.61 (7.40)**	9.04 (6.06)	**16.91 (6.69)**	**23.51 (7.50)**
PC1: Maternal factors	0.87 (0.80, 0.92)	4.14 (5.85)	4.98 (5.02)	**6.86 (5.67)**	**6.15 (6.03)**	2.02 (3.23)	**7.54 (5.52)**	**9.36 (5.87)**
PC2: Free-range chicken factors	0.75 (0.63, 0.84)	0.16 (0.96)	**1.39 (2.32)**	**2.03 (3.27)**	**2.96 (3.19)**	0.85 (2.24)	**1.63 (2.63)**	**2.67 (3.23)**
PC3: Cat factors	0.83 (0.73, 0.89)	1.64 (2.79)	**3.54 (3.22)**	**3.43 (3.82)**	**2.87 (3.18)**	2.04 (2.56)	2.62 (3.35)	**5.62 (3.70)**
PC4: Dairy cattle factors	0.51 (0.31, 0.67)	0.00 (0.00)	**0.89 (1.49)**	0.04 (0.34)	0.00 (0.00)	0.09 (0.47)	0.25 (0.84)	**0.91 (1.62)**
PC5: Dog factors	0.70 (0.54, 0.81)	4.39 (2.23)	**5.02 (1.51)**	3.92 (1.94)	4.63 (2.25)	4.04 (1.97)	**4.87 (1.92)**	**4.95 (1.91)**
Child behavior sub-domain	0.81 (0.70, 0.88)	7.78 (5.19)	**13.26 (6.07)**	**13.54 (7.19)**	**17.52 (7.28)**	11.48 (7.10)	13.15 (6.89)	**14.04 (7.22)**
PC1: Play and mouthing behaviors	0.86 (0.79, 0.92)	7.65 (4.92)	**12.36 (5.55)**	**12.92 (6.42)**	**16.96 (6.88)**	11.35 (6.96)	12.40 (6.22)	12.73 (6.17)
PC2: Animal caregiving and feces behaviors	0.66 (0.49, 0.78)	0.13 (0.77)	**0.90 (2.01)**	0.62 (1.84)	0.59 (1.86)	0.14 (0.71)	**0.75 (1.68)**	**1.31 (2.85)**

*. bold numeric values indicate p-value =<0.05 for bivariate linear regression between scores and community type and animal ownership

Children residing in households that owned at least one type of animal had significantly higher environment sub-domain, behavior sub-domain, and total index exposure scores compared to children in households that did not own any animals, as hypothesized. There were significant differences across PCs, though differences varied by component, as expected. For example, children in households that owned animals had significantly higher scores related to maternal factors (i.e., environment PC1) compared to those residing in households without animals, indicative of the absence of animals in the household for mothers to interact with and care for. Conversely, there was not a significant difference between child play and mouthing scores (i.e., behavior PC1), which was expected given that child play in potentially risky environments and mouthing potentially contaminated objects is not dependent on household animal ownership.

ICC values, based on data from participants who were surveyed twice (n=66), for sub-domain and the overall index indicated good test-retest reliability (Table 4.5). The environment sub-index, behavior sub-index, and overall index had ICC values of 0.79, 0.81, and 0.81, respectively. ICC values for PCs showed moderate to excellent reliability. All five environment sub-domain PCs had moderate to excellent test-retest reliability. For the behavior sub-index, PC1 had good reliability (ICC: 0.86) and PC2 had moderate reliability (ICC: 0.66)

4.5. Discussion

We developed a valid and reliable two-domain, 34-item index to assess fecal-oral child exposure to zoonotic enteropathogens, i.e., the FECEZ Enteropathogens index. This index improves upon and standardizes measurement of child exposure, similar to what other types of validated measures have done (e.g., water and food insecurity).[55-58] Domain-specific scores can be used in aggregate to quantify the degree of exposure, or separately to identify areas of highest risk. Below we describe the major strengths of the FECEZ Enteropathogens index, including the measure's integration of multiple factors to assess exposure, ability to quantify the degree of exposure, and applicability to a broader context.

The FECEZ Enteropathogens index revealed that exposure to zoonotic enteropathogens was ubiquitous among children in northwestern coastal Ecuador. Only two children were not exposed (i.e., had a score of zero), highlighting the shortcomings of the most common measures of exposure currently used – household animal ownership, the presence of animals, and the presence of animal feces.[28] If we had used animal ownership or the presence of animal feces as a measure of exposure in this study, 44% (*n*=132) and 33% (*n*=87) of children would have been classified as having no exposure, respectively (Appendix 6.2 Table S7). The assessment of child exposure using the presence of animals would have been more closely aligned with our results. Seven children (2%) would have been classified as having no exposure using the presence of animals as a proxy, compared to two (<1%) using our index. Still, the presence of animals provides substantially less information compared to our index, which captures many factors to comprehensively assess exposure. Importantly, the measure includes an entire domain with items to assess child behavior, a novel feature given that only 9% of existing exposure measures in our systematic review incorporated human behavior.[28] It also captures multiple environmental factors that are potential sources of enteric pathogens (e.g., presence of specific animals and their feces) and are pre-requisites of exposure.

The FECEZ Enteropathogens index also showed that the degree of exposure varied among Ecuadorian children. We found significant differences in the degree of exposure across communities and by household animal ownership. This suggests that binary measurement of zoonotic exposure, which is common,[28] may be inadequate or inappropriate for the assessment of child exposure. Binary measurement provides insufficient information to identify individuals at highest risk if all children are in fact exposed to some degree and are classified as such. Conversely, bias may be introduced if children are misclassified as unexposed,[59] which is more likely when using binary measures. Our index overcomes these limitations by assessing the magnitude of exposure, and is more appropriate given the pervasiveness of animals, animal feces, and child exposure in LMICs. The FECEZ Enteropathogens index produces a composite, continuous value that allows for the assessment of relative intensity of and variation in

exposure and may decrease the likelihood of exposure misclassification. Future research is needed to examine the relationship between the degree of exposure and child outcomes. Using the continuous FECEZ Enteropathogens measure could enable researchers to identify individuals at high risk and determine if there is a threshold effect where health risks increase after a specific amount of exposure.

Child exposure scores produced using the FECEZ Enteropathogens index were reliable and valid, suggesting that the measure can be used broadly. We found that the domain-specific and overall indices had good test-retest reliability, and exposure scores were significantly different across known-groups, demonstrating construct validity. Expert review and cognitive interviews during the item development phase strengthened the index's ability to adequately measure exposure (i.e., content validity). Engaging urban and rural communities with different types of animals and husbandry practices increases the final measure's generalizability, as does our use of existing exposure measures to create and evaluate the index.

Survey items, scoring instructions, and recommendations for the FECEZ Enteropathogens index are publicly available on OSF.[60] Future studies can use the 34 items that we identified in this study to assess child exposure. However, to help further refine the index for broad use and to ensure that exposure is comprehensively assessed in varying contexts, we recommend asking about the presence of and feces from the types of animals that are relevant to the research context and known to be of high concern for pathogens transmitted in animal feces.[16] Because the FECEZ Enteropathogens index consists of causal or formative indicators (as indices do generally[30,61,62]), the absence of specific types of animals in this Ecuadorian study does not mean that they are not part of the construct, 'child exposure to zoonotic enteric pathogens.' In our context, we found that dogs, dairy cattle, cats, and free-range chickens were contributing to child exposure, which are all known to transmit four of the five pathogens that have been identified as of highest concern for pathogens transmitted in animal feces (i.e., Campylobacter spp., non-typhoidal Salmonella, Cryptosporidium, and Toxoplasma gondii).[16] Other types of animals can also transmit these pathogens (e.g., swine can transmit non-typhoidal Salmonella and Cryptosporidium), and

there are many other pathogens with potentially important transmission in many types of animal feces (e.g., shiga toxin E. coli, Toxocara canis/Toxocara cati).[16] A list of animals to consider based on our research and the literature is publicly available.[60]

Strengths and Limitations

A strength of this research is its' multi-phase, rigorous approach to measurement development and evaluation. Use of qualitative interviews, a systematic review, expert review, and cognitive interviews for item development strengthen the measure's content validity. Items serve as proxies to capture the components of exposure and many exposure pathways, improving upon existing exposure measures that only assess one aspect of exposure. However, this measure is limited by its' inability to be a proxy for every single potential animal feces exposure pathway. The measure does not directly assess pathways related to food, flies, and fluids (water), which are challenging to assess through survey and were therefore not included. Still, assessment of the final measure demonstrates good construct validity and test-retest reliability. Additionally, we were able to collect data from four study sites that differ, for example, by size, infrastructure, and livelihood systems. The diverse sample strengthens the external validity of the final measure, although testing in varied geographic locations is needed to further assess the measure's generalizability. A limitation is our inability to examine the measure's ability to predict future outcomes (i.e., predictive validity), which we were unable to do because time and resource constraints prevented us from collecting data at varied time points. We were also limited by the lack of a "gold standard" measure of child exposure to zoonotic enteric pathogens, which made it impossible for us to assess how the measure performs compared to existing measures (i.e., concurrent validity). Lastly, our unweighted scoring approach may be less precise than a weighted approach that allows item scores to be based on their contribution to the component or factor. However, studies have found that weighting only improves precision moderately, makes interpretation challenging, and inhibits across-study comparisons.[30,51] Producing unweighted scores is more user friendly, and will facilitate the standardization of exposure measurement and comparison of scores across studies.

Conclusion

We created and validated an index to measure fecal-oral child exposure to zoonotic enteropathogens (the FECEZ Enteropathogens index), and assessed child exposure across communities in northwestern coastal Ecuador. The index includes environment and behavior sub-domains, improving upon existing measures by capturing the multidimensionality of the construct and including more proximal exposure factors. This measure can be used to develop, implement, and measure the effectiveness of interventions that aim to reduce child exposure to zoonotic enteric pathogens. It can also be used to determine if agriculture and development programming focused on animal husbandry have unintended consequences for child health. Future research can explore the relationship between exposure to zoonotic enteropathogens and health outcomes.

4.6. References

1. Barredo L, Agyepong I, Liu G, Reddy S. Ensure healthy lives and promote well-being for all at all ages. *UN Chronicle*. 2015;51(4):9-10.

2. Hug L, Alexander M, You D, Alkema L, for Child UI-aG. National, regional, and global levels and trends in neonatal mortality between 1990 and 2017, with scenario-based projections to 2030: a systematic analysis. *The Lancet Global Health*. 2019;7(6):e710-e720.

3. Lozano R, Fullman N, Abate D, et al. Measuring progress from 1990 to 2017 and projecting attainment to 2030 of the health-related Sustainable Development Goals for 195 countries and territories: a systematic analysis for the Global Burden of Disease Study 2017. *The lancet*. 2018;392(10159):2091-2138.

4. Paulson KR, Kamath AM, Alam T, et al. Global, regional, and national progress towards Sustainable Development Goal 3.2 for neonatal and child health: all-cause and cause-specific mortality findings from the Global Burden of Disease Study 2019. *The Lancet*. 2021;398(10303):870-905.

5. Roth GA, Abate D, Abate KH, et al. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*. 2018/11/10/ 2018;392(10159):1736-1788. doi:https://doi.org/10.1016/S0140-6736(18)32203-7

6. Reiner RC, Wiens KE, Deshpande A, et al. Mapping geographical inequalities in childhood diarrhoeal morbidity and mortality in low-income and middle-income countries, 2000–17: analysis for the Global Burden of Disease Study 2017. *The Lancet*. 2020/06/06/ 2020;395(10239):1779-1801. doi:https://doi.org/10.1016/S0140-6736(20)30114-8

7. Prüss-Ustün A, Wolf J, Bartram J, et al. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. *International journal of hygiene and environmental health*. 2019;222(5):765-777.

8. Walker CLF, Rudan I, Liu L, et al. Global burden of childhood pneumonia and diarrhoea. *Lancet*. Apr 20 2013;381(9875):1405-1416. doi:10.1016/s0140-6736(13)60222-6

9. Perin J, Mulick A, Yeung D, et al. Global, regional, and national causes of under-5 mortality in 2000–19: an updated systematic analysis with implications for the Sustainable Development Goals. *The Lancet Child & Adolescent Health*. 2022;6(2):106-115. doi:10.1016/S2352-4642(21)00311-4

10. Lunn P. The impact of infection and nutrition on gut function and growth in childhood. *Proc Nutr Soc*. 2000;59:147.

11. Lunn PG. Growth retardation and stunting of children in developing countries. *British Journal of Nutrition*. 2002;88(2):109-110.

12. Guerrant RL, Oria RB, Moore SR, Oria MO, Lima AA. Malnutrition as an enteric infectious disease with long-term effects on child development. *Nutr Rev*. Sep 2008;66(9):487-505. doi:10.1111/j.1753-4887.2008.00082.x

13. Guerrant RL, DeBoer MD, Moore SR, Scharf RJ, Lima AA. The impoverished gut--a triple burden of diarrhoea, stunting and chronic disease. *Nat Rev Gastroenterol Hepatol*. Apr 2013;10(4):220-9. doi:10.1038/nrgastro.2012.239

14. Keusch GT, Denno DM, Black RE, et al. Environmental Enteric Dysfunction: Pathogenesis, Diagnosis, and Clinical Consequences. *Clin Infect Dis*. 2014:S207-12. vol. Suppl 4.

15. Petri WA, Jr., Miller M, Binder HJ, Levine MM, Dillingham R, Guerrant RL. Enteric infections, diarrhea, and their impact on function and development. *J Clin Invest*. Apr 2008;118(4):1277-90. doi:10.1172/jci34005

16. Delahoy MJ, Wodnik B, McAliley L, et al. Pathogens transmitted in animal feces in low- and middle-income countries. *International Journal of Hygiene and Environmental Health*. 2018/05/01/ 2018;221(4):661-676. doi:https://doi.org/10.1016/j.ijheh.2018.03.005

17. Penakalapati G, Swarthout J, Delahoy MJ, et al. Exposure to Animal Feces and Human Health: A Systematic Review and Proposed Research Priorities. *Environmental science & technology*. 2017;51(20):11537-11552. doi:10.1021/acs.est.7b02811

18. Prendergast AJ, Gharpure R, Mor S, et al. Putting the "A" into WaSH: a call for integrated management of water, animals, sanitation, and hygiene. *The Lancet Planetary Health*. 2019;3(8):e336-e337.

19. Pickering AJ, Null C, Winch PJ, et al. The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health*. 2019;7(8):e1139-e1146.

20. Gharpure R, Mor SM, Viney M, et al. A One Health Approach to Child Stunting: Evidence and Research Agenda. *The American Journal of Tropical Medicine and Hygiene*. 2021;104(5):1620.

21. Barnes AN, Anderson JD, Mumma J, Mahmud ZH, Cumming O. The association between domestic animal presence and ownership and household drinking water contamination among peri-urban communities of Kisumu, Kenya. *PloS one*. 2018;13(6):e0197587-e0197587. doi:10.1371/journal.pone.0197587

22. Barnes AN, Mumma J, Cumming O. Role, ownership and presence of domestic animals in peri-urban households of Kisumu, Kenya. *Zoonoses and public health*. 2018/02// 2018;65(1):202-214. doi:10.1111/zph.12429

23. Ngure FM, Humphrey JH, Mbuya MNN, et al. Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *The American journal of tropical medicine and hygiene*. 2013;89(4):709-716. doi:10.4269/ajtmh.12-0568

24. Lowenstein C, Waters WF, Roess A, Leibler JH, Graham JP. Animal Husbandry Practices and Perceptions of Zoonotic Infectious Disease Risks Among Livestock Keepers in a Rural Parish of Quito, Ecuador. *The American journal of tropical medicine and hygiene*. 2016;95(6):1450-1458. doi:10.4269/ajtmh.16-0485

25. Thomas ED. *Hens, housing, and hygiene: formative research in rural Bangladesh for interventions to separate young children from poultry and poultry feces*. Johns Hopkins University; 2021.

26. Ercumen A, Pickering AJ, Kwong LH, et al. Animal feces contribute to domestic fecal contamination: evidence from E. coli measured in water, hands, food, flies, and soil in Bangladesh. *Environmental science & technology*. 2017;51(15):8725-8734.

27. Berendes DM, Yang PJ, Lai A, Hu D, Brown J. Estimation of global recoverable human and animal faecal biomass. *Nature Sustainability*. 2018;1(11):679-685.

28. Ballard AML, Nick; Haardoerfer, Regine; Freeman, Matthew C; Levy, Karen; Caruso, Bethany A. Measurement in the study of human exposure to animal feces: A systematic review and audit. osf.io/d2nxc

29. Boateng GO, Neilands TB, Frongillo EA, Melgar-Quiñonez HR, Young SL. Best Practices for Developing and Validating Scales for Health, Social, and Behavioral Research: A Primer. Review. *Frontiers in Public Health*. 2018-June-11 2018;6(149)doi:10.3389/fpubh.2018.00149

30. de Vet HCW, Terwee CB, Mokkink LB, Knol DL. *Measurement in Medicine : A Practical Guide*. Cambridge University Press; 2011.

31. Diamantopoulos A, Winklhofer HM. Index construction with formative indicators: An alternative to scale development. *Journal of marketing research*. 2001;38(2):269-277.

32. Jepson WE, Wutich A, Colllins SM, Boateng GO, Young SL. Progress in household water insecurity metrics: a cross-disciplinary approach. *WIREs Water*. 2017;4(3):e1214. doi:https://doi.org/10.1002/wat2.1214

33. MacRae ER, Clasen T, Dasmohapatra M, Caruso BA. 'It's like a burden on the head': Redefining adequate menstrual hygiene management throughout women's varied life stages in Odisha, India. *PLOS ONE*. 2019;14(8):e0220114. doi:10.1371/journal.pone.0220114

34. Thomson J, Amery F, Channon M, Puri M. What's missing in MHM? Moving beyond hygiene in menstrual hygiene management. *Sexual and Reproductive Health Matters*. 2019/01/01 2019;27(1):12-15. doi:10.1080/26410397.2019.1684231

35. Council NR. Exposure science in the 21st century: a vision and a strategy. 2012;

36. Lee GO, Eisenberg JNS, Uruchima J, et al. Gut microbiome, enteric infections and child growth across a rural–urban gradient: protocol for the ECoMiD prospective cohort study. *BMJ Open*. 2021;11(10):e046241. doi:10.1136/bmjopen-2020-046241

37. City Population: Republic of Ecuador, 2010 census. https://www.citypopulation.de/en/ecuador/

38. Smith SM, Montero L, Paez M, et al. Locals get travellers' diarrhoea too: risk factors for diarrhoeal illness and pathogenic Escherichia coli infection across an urban-rural gradient in Ecuador. *Tropical Medicine & International Health*. 2019;24(2):205-219. doi:https://doi.org/10.1111/tmi.13183

39. Lee GO, Whitney HJ, Blum AG, et al. Household coping strategies associated with unreliable water supplies and diarrhea in Ecuador, an upper-middle-income country. *Water research*. 2020;170:115269-115269. doi:10.1016/j.watres.2019.115269

40. Creswell JW, Creswell JD. *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications; 2017.

41. Garcia CM, Eisenberg ME, Frerich EA, Lechner KE, Lust K. Conducting go-along interviews to understand context and promote health. *Qual Health Res*. Oct 2012;22(10):1395-403. doi:10.1177/1049732312452936

42. Carpiano RM. Come take a walk with me: the "go-along" interview as a novel method for studying the implications of place for health and well-being. *Health Place*. Mar 2009;15(1):263-72. doi:10.1016/j.healthplace.2008.05.003

43. Guadagnoli E, Velicer WF. Relation of sample size to the stability of component patterns. *Psychological bulletin*. 1988;103(2):265.

44. Osborne JW, Costello AB. Sample size and subject to item ratio in principal components analysis. *Practical Assessment, Research, and Evaluation*. 2004;9(1):11.

45. Jolliffe IT, Cadima J. Principal component analysis: a review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 2016;374(2065):20150202.

46. Kaiser HF. A second generation little jiffy. *Psychometrika*. 1970/12/01 1970;35(4):401-415. doi:10.1007/BF02291817

47. BARTLETT MS. THE EFFECT OF STANDARDIZATION ON A χ2 APPROXIMATION IN FACTOR ANALYSIS. *Biometrika*. 1951;38(3-4):337-344. doi:10.1093/biomet/38.3-4.337

48. *Gifi: Multivariate Analysis with Optimal Scaling*. Version R package version 0.3-10. 2022. https://CRAN.R-project.org/package=Gifi

49. *RStudio: Integrated Development for R*. RStudio, PBC; 2020. http://www.rstudio.com/

50. Dunteman GH. *Principal Components Analysis*. 1989. Accessed 2020/04/27. https://methods.sagepub.com/book/principal-components-analysis

51. Mair P. *Modern psychometrics with R*. Springer; 2018.

52. Haardörfer R. Taking quantitative data analysis out of the positivist era: Calling for theory-driven data-informed analysis. *Health Education & Behavior*. 2019;46(4):537-540.

53. *psych: Procedures for Psychological, Psychometric, and Personality Research*. Version R package version 2.2.5. 2022. https://CRAN.R-project.org/package=psych

54. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*. Jun 2016;15(2):155-63. doi:10.1016/j.jcm.2016.02.012

55. Cafiero C, Viviani S, Nord M. Food security measurement in a global context: The food insecurity experience scale. *Measurement*. 2018/02/01/ 2018;116:146-152. doi:https://doi.org/10.1016/j.measurement.2017.10.065

56. Saint Ville A, Po JYT, Sen A, Bui A, Melgar-Quiñonez H. Food security and the Food Insecurity Experience Scale (FIES): ensuring progress by 2030. *Food Security*. 2019/06/01 2019;11(3):483-491. doi:10.1007/s12571-019-00936-9

57. Stoler J, Miller JD, Adams EA, et al. The Household Water Insecurity Experiences (HWISE) Scale: comparison scores from 27 sites in 22 countries. *Journal of Water, Sanitation and Hygiene for Development*. 2021;11(6):1102-1110. doi:10.2166/washdev.2021.108

58. Young SL, Boateng GO, Jamaluddine Z, et al. The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. *BMJ Global Health*. 2019;4(5):e001750. doi:10.1136/bmjgh-2019-001750

59. Flegal KM, BROWNIE C, HAAS J. The effects of exposure misclassification on estimates of relatwe risk. *American journal of epidemiology*. 1986;123(4):736-751.

60. Ballard AM; Haardörfer R; Corozo Angulo B; Freeman MC; EIsenberg JLGLKCB. Data from: Tools for the development and validation of a survey to measure fecal-oral child exposure to zoonotic enteropathogens: The FECEZ index. 2023.

61. Polites GL, Roberts N, Thatcher J. Conceptualizing models using multidimensional constructs: a review and guidelines for their use. *European Journal of Information Systems*. 2012;21(1):22-48.

62. Roberts N, Thatcher J. Conceptualizing and testing formative constructs: Tutorial and annotated example. *ACM sigmis database: The database for Advances in Information Systems*. 2009;40(3):9-39.

Chapter 5. Summary, implications and future directions

5.1. Summary of findings

While it is well documented that inadequate and unsafe water, sanitation, and hygiene (WASH) is a major cause of enteric infections,[1-5] evidence suggests that current WASH strategies that aim to reduce infections by intervening on human feces alone are not sufficient to address all key pathogen sources and transmission pathways.[5-8] Exposure to animal feces is increasingly recognized as a significant transmission route of enteric pathogens, especially among children in low- and middle-income countries (LMICs) where animals and their feces are prominent in domestic environments.[9-15] The goal of this dissertation was to better understand if, why, how, and to what extent children under two are exposed to animal feces. Findings from this research fill critical research gaps to improve and inform the conception and measurement of child exposure to zoonotic enteric pathogens, which can enable and expand researchers' and practitioners' ability to assess exposure and develop and evaluate interventions.

Research aim 1 investigated if and how children are exposed to zoonotic enteric pathogens in northwestern coastal Ecuador. We conducted qualitative interviews with mothers of children aged 6-18 months that owned and did not own animals. We found myriad opportunities for young children to be exposed to fecal pathogens of domesticated animals, regardless of whether or not their household owned animals. Our results support existing evidence that children may ingest environmental media or feces contaminated with enteric pathogens from animals, and highlight three opportunities for future research on child exposure. First, we found that animal feces disposal practices used by mothers (e.g. rinsing feces into ditches, throwing feces into surrounding areas) may increase contamination of the environment through various pathways as suggested elsewhere,[16-18] which is currently underexplored in the literature.[19] Our findings suggest that identification and incorporation of safe practices along the animal feces management pathway may be an effective, practical approach for intervening on the many exposure pathways related to animal feces. Second, children regularly spent time in places other than their household where animals and animal feces were present. Thus, current approaches to assess and intervene

on exposure that overwhelmingly focus on the household[20] are potentially missing significant locations where children are exposed. A better understanding of where and how children are exposed across multiple settings will be critical to effectively assess and intervene on zoonotic exposures. Third, although child behaviors and environments were primarily experienced through and determined by mothers, children spent considerable time with others (e.g., siblings, grandparents, and neighbors). Existing research has primarily engaged mothers,[21-31] but our findings suggest that other people could also play a role in child exposure. Identifying the various caregivers and actors who frequently interact with children could elucidate how multiple individuals mediate child exposure, and present significant opportunities for intervention.

Research aim 2 reviewed existing approaches to the measurement of human exposure to animal feces in LMICs. We systematically searched peer-reviewed and gray literature databases for studies with quantitative exposure measures and classified each measure in two ways. First, we categorized measures into 'Exposure Components' that we identified *a priori* (i.e., Animal, Environmental, Human Behavioral); one additional Component (Evidence of Exposure) inductively emerged. Second, we classified measures based on the exposure science concept they assessed – source, contaminant, reservoir or vector, behavior, route, or outcome. Results revealed that existing measurement approaches are diverse. Most measures are distal from exposure and do not account for the multiple causal conditions that constitute exposure. Our findings provide important considerations for improving measurement of human exposure to animal feces. Additional research is needed to create and validate a multidimensional measure, which could help advance our understanding of the health effects of animal fecal-related exposures and increase ability to identify high risk areas for intervention.

Research aim 3 developed a novel measure for fecal-oral child exposure to zoonotic enteropathogens (the FECEZ Enteropathogens index) and assessed exposure among children under five in northwestern coastal Ecuador. We used a sequential mixed methods approach, leveraging data from interviews conducted for aim 1, the systematic review conducted for aim 2, and surveys with mothers. The final index consisted of

seven interpretable components and 34 variables that evaluate environmental and behavioral exposure factors. Index scores showed that only two children had no exposure (i.e., a score of zero). In contrast, if animal ownership was used as a proxy for exposure, which is a common approach,[20] 44% of children would have been classified as having no exposure. Comparing scores across communities and household animal ownership revealed that the relevancy of some exposure factors varied, while others were applicable more broadly. Our results highlight the complexity of child exposure that is not captured with most existing measures that assess a single attribute of exposure. The multidimensional FECEZ Enteropathogens index provides the opportunity to assess relative intensity of and variation in exposure. Using the FECEZ Enteropathogens index may be critical to the development of interventions and identification of high-risk areas by improving researchers' ability to differentiate between exposure factors that are relevant to few individuals and those that are applicable more broadly.

5.2. Limitations

Research aim 1 used a rigorous qualitative approach, though there are some limitations to the findings. First, our final sample did not include children between 6-10 months old as initially targeted due to circumstances surrounding COVID-19 and recruitment from the larger ECoMiD cohort. Specifically, few children aged 6-10 months old were enrolled in the cohort at the time of recruitment. There may be factors unique to younger or older children that were not captured in our sample. Sample sizes were uneven across communities because there were few cohort participants in rural communities during data collection, which could impact the quality of community comparisons. Second, data may have been incomplete or inaccurate because we exclusively interviewed mothers about child exposure. Mothers were not always the main or sole caregiver. Interviewing other types of caregivers (e.g., grandmothers, older siblings) may provide additional information.

Results from aim 2 were limited by the types of studies included in the review. We intentionally used broad inclusion criteria to capture a large body of literature because of the novelty of the review, and did not consider methodological rigor in our inclusion criteria. Studies were included regardless of quality.

Conversely, our exclusion criteria may have led us to miss important studies. We were limited to studies written in English and Spanish, and did not include studies focused on occupational exposure to animal feces. Lastly, our search may have been biased toward public health literature and may miss critical studies from other disciplines (e.g., agriculture).

Research aim 3 used a multi-phase approach and measurement development best practices,[32] but was limited by its inability to examine the measure's capacity to predict future outcomes (i.e., predictive validity). We were unable to collect data at multiple time points to assess predictive validity because of time and resource constraints. We were also limited by the of a "gold standard" measure, which made it impossible for us to assess how the measure performs compared to existing measures (i.e., concurrent validity). Lastly, we relied on an unweighted scoring approach, which may be less precise compared to a weighted approach that scores items based on their contribution to the component or factor. Though, producing unweighted scores is more user friendly, and will facilitate the standardization of exposure measurement and comparison of scores across studies.

5.3. Implications

There are four key implications of this work for the study of child exposure to zoonotic enteric pathogens.

1. Child exposure to zoonotic enteric pathogens occurs in multiple settings.

Results from this dissertation support evidence that children in LMICs may ingest environmental media or feces contaminated with enteric pathogens from animals in their household environment. Animal feces is largely produced in domestic environments,[33] and child exposure to it is associated with diarrhea and malnutrition.[20,34-37] In Bangladesh, the presence of animal feces in the household compound was found to increase the odds of child diarrhea by 25%.[35] A study in Western Kenya found that the odds of child moderate-to-severe diarrhea were 7.5 times higher in households where fresh rodent excreta was observed frequently.[38] In the Democratic Republic of the Congo, the presence of animal feces in the child's sleeping space and mouthing of animal feces were found to be significantly associated with linear growth

faltering.[39] Studies in Bangladesh and Ethiopia found that the presence of animal feces in the household compound was negatively associated with child height-for-age Z-scores.[35] Similarly, our qualitative and quantitative findings in aims 1 and 3 showed that animals and their feces were common in domestic spaces where children spent time. We did not conduct analyses to examine associations with health outcomes.

This dissertation provides novel evidence about other settings where children may be exposed to zoonotic enteric pathogens. Research aim 1 revealed that child exposure may not solely occur at the household. Children visited and spent time in multiple locations on a typical day – in addition to their household – where animals and animal feces were present (e.g., parks, family members' households). Sole focus on the household environment could provide inaccurate and/or incomplete data on exposure. This is congruent with studies in Kenya and Haiti that found that enteric pathogen exposure can occur through numerous pathways in various spaces where children spend time.[40,41] Research aim 2 found that most studies have assessed human exposure to animal feces in domestic spaces and rarely include other settings. Together, findings from aims 1 and 2 suggest that significant sites of child exposure are currently absent in research. A better understanding of the various settings where children are exposed will be critical to effectively assess and intervene on exposure. Researchers and practitioners will also need to consider how exposure across multiple locations could collectively impact child health.

2. The interpersonal environment influences child exposure to zoonotic enteric pathogens.

Child behavior and environments are primarily experienced through and determined by their caregivers.[25,26,28,42] Our findings support that mothers are significant mediator of fecal exposures. In Bangladesh, children of mothers with visibly dirty hands had elevated markers of environmental enteropathy, a condition that is associated with stunting and is thought to arise from repeat enteric infections.[43] Studies in Ethiopia found that lack of maternal hand washing was significantly associated with child diarrhea.[44] In research aim 1, mothers reported frequent contact with animal feces and rarely used scoops to collect feces. Studies have found that removing feces without using scoops or a similar

tool increases hand contamination[16,17] and can result in child interpersonal environments being contaminated with enteric pathogens.

Findings from aims 1 and 3 suggest that other individuals beyond mothers can also be mediators of child exposure. In aim 1, we found that children spent considerable time with others (e.g., siblings, grandparents, and neighbors) who had regular contact with animals and animal feces. In aim 3, we found that having a household member apart from the mother who works or cares for an animal was a key environmental component of child exposure, as were many maternal factors. These results highlight that mothers and other individuals are part of a child's interpersonal environment and can influence the likelihood of child exposure. Understanding the role that various caregivers and actors play in exposure can help elucidate transmission pathways that may currently be missed.

3. Safe animal feces management can mitigate child exposure to zoonotic enteric pathogens.

The results from this dissertation highlight that practices such as free-range husbandry and not disposing or safely managing of animal feces pose a risk to children, which is aligned with existing research.[5-7,10,19,41,45,46] Researchers have emphasized the important role that animal husbandry and feces management practices can play in fecal contamination of the environment and child exposure to zoonotic enteric pathogens.[5-7,19] In Ethiopia, less animal feces was present and child hands were cleaner in households where chicken coops were enclosed, had fencing, and were located further from the home.[47] However, chicken owners allowed their animals to roam freely to forage for food or have more space, both of which were seen as beneficial to animal health. A study in Burkina Faso found that the presence of chicken feces in the household compound was associated with the number of poultry kept in the compound, livestock having access to drinking water sources, and a child being visibly dirty. The presence of chicken feces in the household compound was significantly associated with lower weight-for-height Z-scores in children under five years of age.[37] Similarly, we found that proximity of and interactions between animals, their feces, and children are part of a broader system that must be considered in order to identify solutions to zoonotic enteric pathogen exposure. In aim 3, children were exposed to animals and animal feces

regardless of animal ownership, though the magnitude of exposure varied by community. Similar patterns emerged in aim 1. Animals and animal feces were present to varying degrees in households that did and did not own animals, a result of owned and free-roaming animals defecating throughout domestic spaces.

Findings from this dissertation suggest that safe animal feces management practices that go beyond removal and disposal could be critical to intervene on child exposure. Practices reported in research aim 1 are consistent with child feces practices reported in other studies.[16-18,31] The animal feces management practices reported by mothers have been found to increase contamination of the environment through various pathways in child feces management studies.[16] Many mothers reported throwing animal feces into surrounding areas, which can lead to increased exposure risks from flies, animals, or rain. Some rinsed animal feces with water, potentially spreading fecal contamination rather than eliminating it. Animal feces near child domestic and play areas were typically removed, but surfaces were inconsistently cleaned with soap or disinfectants. In the absence of soap or disinfectants, increased environmental fecal contamination can remain after feces are removed.[16] These findings suggest that animal feces removal and disposal may contaminant the environment through pathways that are similar to those identified in child feces management research. Building upon existing research on the child feces management pathway, which identified needs beyond feces removal and disposal, will be advantageous and can lead to integrated approaches that reduce both child and animal feces contamination of the environment. Further investigating animal feces management can help identify practices that are significant sources of contamination and opportunities for intervention. Developing safe animal feces management practices may be more practical and effective for reducing environmental contamination compared to interventions that target husbandry practices (e.g., corralling), which require a suit of interventions (e.g., consistent and sufficient feed supplies, adequate and secure housing) that can be cost prohibitive, logistically and behaviorally burdensome, and socio-culturally incompatible in some cases.[19,47-50]

4. **Proximal and multidimensional measurement of child exposure to zoonotic enteric pathogens can improve the assessment of health effects and development of interventions.**

This dissertation emphasizes the need and potential for improved measurement of child exposure to zoonotic enteric pathogens, which has been called for by many researchers.[5,20,51,52] Results from aim 2 revealed that existing measurement approaches are diverse, distal from exposure, and do not account for the multiple causal conditions that constitute exposure. Most measures only assessed one aspect of exposure, typically about animals or the environment. A small proportion of measures captured human behaviors, even though behavior is critical and more proximal to exposure. Research aims 1 and 3 highlighted the multitude of play, mouthing, and animal-related behaviors that are significant for child exposure to zoonotic enteric pathogens. A study in Western Uganda found that household behavioral factors such as those related to corralling and feces disposal play a significant role in child exposure, and emphasized the need for indicators that more comprehensively characterize exposure.[19] It is well documented that the assessment of the health effects of a particular contaminant greatly improves when more proximal measures of exposure are used.[53] Our findings suggest that current measurement of child exposure to zoonotic enteric pathogens, which largely excludes behavior, limits assessment of health outcomes and therefore identification of areas of high risk for intervention.

Results from research aims 1, 2, and 3 provide important considerations to inform and improve measurement. First, our findings demonstrate that child exposure to zoonotic enteric pathogens is the result of many factors, and it has not yet been clearly demonstrated whether one particular factor, more than any other, affects human health or exerts an effect by itself. Measuring the many attributes of exposure will be important to more comprehensively and accurately assess exposure and its' effect on human health. Measuring multiple attributes will allow researchers to examine how different factors, by themselves and collectively, impact health. Second, child exposure scores calculated using our novel index suggest that exposure misclassification may be common in existing research. Only two out of 297 children had no exposure (i.e., a score of zero), whereas 44% of children would have been classified as having no exposure based on animal ownership. By measuring multiple environmental and behavioral exposure factors, a composite, continuous value of exposure can be calculated, which may decrease the

likelihood of exposure misclassification and improve researchers' ability to detect effects on human health. The novel measure we developed and validated provides the opportunity to improve and standardize measurement. Researchers can apply it in various contexts to evaluate its' generalizability and cross-cultural equivalence. Third, as Implications 1 through 3 suggest, current understanding of child exposure is limited and may result in incomplete and/or inaccurate exposure assessment. Using the exposure science framework (i.e., the source-to-outcome continuum) to delineate the elements of exposure and the point at which feces enters the body can elucidate what is critical to the measurement of child exposure to zoonotic enteric pathogens and how one might develop more precise measurement approaches.

5.4. Future directions

This dissertation addresses critical research gaps to improve and inform understanding and measurement of child exposure to zoonotic enteric pathogens. We characterized child zoonotic exposures, assessed current measurement approaches, developed and evaluated a novel measure of child exposure, and quantified exposure among children under five years of age. Our findings provide significant evidence for public health research and practice, and highlight opportunities for future research.

Exposure beyond the household. Children spent substantial time in multiple locations outside of their household where animals and animal feces were prominent. Qualitative interviews ascertained some information about these locations, but IDIs were largely focused on household conditions. Additional research should attempt to understand opportunities for young children to be exposed to zoonotic pathogens at locations beyond the household, and assess how much time children spend at various locations. Significant locations beyond the household could be identified to examine how exposure across multiple locations could collectively impact child health. Future research could expand on our exposure index to develop a measure that captures exposure at the household and in other places.

The interpersonal environment. Child exposure was influenced by mothers and other individuals, highlighting that many people may mediate exposure and constitute the child's interpersonal environment. Qualitative findings revealed that children interacted with and were cared for by many people who habitually had contact with animals and animal feces. Quantitative results showed that interactions with animals and animal feces among mothers and other household members were key environmental components of child exposure to zoonotic enteric pathogens. Identification of the various caregivers and actors who frequently interact with children could elucidate how mothers and other individuals mediate child exposure, and present opportunities for intervention.

Safe animal feces management practices. Animal feces removal and disposal practices reported by mothers, such as rinsing feces into ditches and throwing feces into surrounding areas, may increase contamination of the environment through various pathways.[16-18] Animal removal and disposal practices were similar to child feces practices reported in other studies.[16-18,31] Research on child feces management suggests that unsafe practices along the feces management pathway – which includes defecation, feces removal and disposal, defecation location cleaning, anal cleansing, and handwashing – increase environmental contamination.[16-18,31] To establish safe animal feces management practices, future research should assess unsafe practices and feces contamination using observation and microbiology methods. The management pathway established for child feces can inform data collection at key points to validate the animal feces management pathway, with changes made as relevant. Building upon existing research on child feces management will enable the development of an integrated exposure assessment and control approach that captures the many enteric pathogen exposure pathways related to animal and child feces. Differences by animal type should also be examined. Different types of animals defecate at different frequencies, have different types and sizes of stool, and may or may not bury their feces. We found that factors such as these led to different removal and disposal practices, and have implications for contamination along the AFM pathway.

Measurement. We developed and validated a novel measure of child exposure to zoonotic enteric pathogens. The measure should be applied in various contexts and across cultures to evaluate its' generalizability and cross-cultural equivalence. Due to time and resource constraints, we were not able to collect data at varied time points. Longitudinal assessment of exposure could enable the assessment of the measure's predictive validity.

Health impacts. Mothers engaged in qualitative and quantitative research reported myriad opportunities for young children to be exposed to fecal pathogens from animals. However, we did not examine associations between child exposure and health outcomes using the novel FECEZ Enteropathogens index. Future research could use our validated, multidimensional measure to explore how exposure to zoonotic enteropathogens affects child health outcomes, including enteric infections, diarrhea, and growth. By measuring multiple attributes of exposure, researchers could examine if and how different factors, by themselves and collectively, impact health. Using a composite, continuous measure of exposure could enable the assessment of the degree of exposure as opposed to binary exposure assessment. The relationship between the degree of exposure and child outcomes could be investigated to determine if there is a threshold effect where health risks increase after a specific amount of exposure. Items on child diarrhea, fever, and blood in stool were included in the same survey that included exposure items for research aim 3. Bivariate and multivariable analyses can be performed to test the association between child exposure and diarrhea, fever, and blood in stool; examine if factors impact health by themselves and/or collectively; and assess if there is a threshold effect.

5.5. References

1. Petri WA, Jr., Miller M, Binder HJ, Levine MM, Dillingham R, Guerrant RL. Enteric infections, diarrhea, and their impact on function and development. *J Clin Invest*. Apr 2008;118(4):1277-90. doi:10.1172/jci34005.

2. Goddard FG, Pickering AJ, Ercumen A, Brown J, Chang HH, Clasen T. Faecal contamination of the environment and child health: a systematic review and individual participant data meta-analysis. *The Lancet Planetary Health*. 2020;4(9):e405-e415.

3. Kosek MN, Ahmed T, Bhutta Z, et al. Causal pathways from enteropathogens to environmental enteropathy: findings from the MAL-ED birth cohort study. *EBioMedicine*. 2017;18:109-117.

4. Gizaw Z, Yalew AW, Bitew BD, Lee J, Bisesi M. Fecal indicator bacteria along multiple environmental exposure pathways (water, food, and soil) and intestinal parasites among children in the rural northwest Ethiopia. *BMC gastroenterology*. 2022;22(1):84-84. doi:10.1186/s12876-022-02174-4.

5. Cumming O, Cairncross S. Can water, sanitation and hygiene help eliminate stunting? Current evidence and policy implications. *Maternal & child nutrition*. 2016;12:91-105.

6. Cumming O, Arnold BF, Ban R, et al. The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. *BMC medicine*. 2019;17(1):1-9.

7. Pickering AJ, Null C, Winch PJ, et al. The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health*. 2019;7(8):e1139-e1146.

8. Prendergast AJ, Gharpure R, Mor S, et al. Putting the "A" into WaSH: a call for integrated management of water, animals, sanitation, and hygiene. *The Lancet Planetary Health*. 2019;3(8):e336-e337.

9. Barnes AN, Anderson JD, Mumma J, Mahmud ZH, Cumming O. The association between domestic animal presence and ownership and household drinking water contamination among peri-urban communities of Kisumu, Kenya. *PloS one*. 2018;13(6):e0197587-e0197587. doi:10.1371/journal.pone.0197587.

10. Barnes AN, Mumma J, Cumming O. Role, ownership and presence of domestic animals in peri-urban households of Kisumu, Kenya. *Zoonoses and public health*. 2018/02// 2018;65(1):202-214. doi:10.1111/zph.12429.

11. Ngure FM, Humphrey JH, Mbuya MNN, et al. Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *The American journal of tropical medicine and hygiene*. 2013;89(4):709-716. doi:10.4269/ajtmh.12-0568.

12. Lowenstein C, Waters WF, Roess A, Leibler JH, Graham JP. Animal Husbandry Practices and Perceptions of Zoonotic Infectious Disease Risks Among Livestock Keepers in a Rural Parish of Quito, Ecuador. *The American journal of tropical medicine and hygiene*. 2016;95(6):1450-1458. doi:10.4269/ajtmh.16-0485.

13. Gharpure R, Mor SM, Viney M, et al. A One Health Approach to Child Stunting: Evidence and Research Agenda. *The American Journal of Tropical Medicine and Hygiene*. 2021;104(5):1620.

14. Thomas ED. Hens, housing, and hygiene: formative research in rural Bangladesh for interventions to separate young children from poultry and poultry feces. Johns Hopkins University; 2021.

15. Ercumen A, Pickering AJ, Kwong LH, et al. Animal feces contribute to domestic fecal contamination: evidence from E. coli measured in water, hands, food, flies, and soil in Bangladesh. *Environmental science & technology*. 2017;51(15):8725-8734.

16. Bauza V, Majorin F, Routray P, Sclar GD, Caruso BA, Clasen T. Child feces management practices and fecal contamination: A cross-sectional study in rural Odisha, India. *Science of The Total Environment*. 2020/03/20/ 2020;709:136169. doi.org/10.1016/j.scitotenv.2019.136169.

17. Majorin F, Torondel B, Routray P, Rout M, Clasen T. Identifying potential sources of exposure along the child feces management pathway: a cross-sectional study among urban slums in Odisha, India. *The American journal of tropical medicine and hygiene*. 2017;97(3):861.

18. Mugel SG, Clasen TF, Bauza V. Global practices, geographic variation, and determinants of child feces disposal in 42 low-and middle-income countries: An analysis of standardized cross-sectional national surveys from 2016–2020. *International Journal of Hygiene and Environmental Health*. 2022;245:114024.

19. Lowe J, Ercumen A, Prottas C, Harris AR. Exploring the determinants and indicators of poultry feces management behaviors in rural Western Uganda. *The Science of the total environment*. 2022;834:155202-155202. doi:10.1016/j.scitotenv.2022.155202.

20. Penakalapati G, Swarthout J, Delahoy MJ, et al. Exposure to Animal Feces and Human Health: A Systematic Review and Proposed Research Priorities. *Environmental science & technology*. 2017;51(20):11537-11552. doi:10.1021/acs.est.7b02811.

21. Amugsi DA, Mittelmark MB, Lartey A, Matanda DJ, Urke HB. Influence of childcare practices on nutritional status of Ghanaian children: a regression analysis of the Ghana Demographic and Health Surveys. *BMJ Open*. 2014;4(11):e005340. doi:10.1136/bmjopen-2014-005340.

22. Majeed MT, Kiran F. Women's decision making power and child labor: evidence from Pakistan. *Quality & Quantity*. 2019/07/01 2019;53(4):2175-2197. doi:10.1007/s11135-019-00864-y.

23. Ghose B, Feng D, Tang S, et al. Women's decision-making autonomy and utilisation of maternal healthcare services: results from the Bangladesh Demographic and Health Survey. *BMJ Open*. 2017;7(9):e017142. doi:10.1136/bmjopen-2017-017142.

24. Millard AV. A causal model of high rates of child mortality. *Social Science & Medicine*. 1994;38(2):253-268. doi:10.1016/0277-9536(94)90395-6.

25. Mosley WH, Chen LC. An analytical framework for the study of child survival in developing countries. 1984. *Bulletin of the World Health Organization*. 2003;81(2):140-145.

26. Caruso B, Stephenson R, Leon JS. Maternal behavior and experience, care access, and agency as determinants of child diarrhea in Bolivia. *Revista panamericana de salud publica = Pan American journal of public health*. 2010;28(6):429-439. doi:10.1590/s1020-49892010001200004.

27. Rao N, Gazdar H, Chanchani D, Ibrahim M. Women's agricultural work and nutrition in South Asia: From pathways to a cross-disciplinary, grounded analytical framework. *Food Policy*. 2019/01/01/ 2019;82:50-62. doi:https://doi.org/10.1016/j.foodpol.2018.10.014.

28. Kadiyala S, Harris J, Headey D, Yosef S, Gillespie S. Agriculture and nutrition in India: mapping evidence to pathways. *Annals of the New York Academy of Sciences*. 2014;1331(1):43-56. doi:10.1111/nyas.12477.

29. Po JYT, Bukania Z, Muhammad L, Hickey GM. Associations between Maternal Participation in Agricultural Decision-Making and Child Nutrition in Semiarid Kenya. *Journal of Hunger & Environmental Nutrition*. 2019:1-26. doi:10.1080/19320248.2019.1617214.

30. Björkman Nyqvist M, Jayachandran S. Mothers care more, but fathers decide: Educating parents about child health in Uganda. *American Economic Review*. 2017;107(5):496-500.

31. Sosa-Moreno A, Lee GO, Van Engen A, et al. Characterizing Behaviors Associated with Enteric Pathogen Exposure among Infants in Rural Ecuador through Structured Observations. *The American Journal of Tropical Medicine and Hygiene*. 2022;106(6):1747.

32. Boateng GO, Neilands TB, Frongillo EA, Melgar-Quiñonez HR, Young SL. Best Practices for Developing and Validating Scales for Health, Social, and Behavioral Research: A Primer. Review. *Frontiers in Public Health*. 2018-June-11 2018;6(149)doi:10.3389/fpubh.2018.00149.

33. Berendes DM, Yang PJ, Lai A, Hu D, Brown J. Estimation of global recoverable human and animal faecal biomass. *Nature Sustainability*. 2018;1(11):679-685.

34. Zambrano LD, Levy K, Menezes NP, Freeman MC. Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. Jun 2014;108(6):313-325. doi:10.1093/trstmh/tru056.

35. Headey D, Nguyen P, Kim S, Rawat R, Ruel M, Menon P. Is Exposure to Animal Feces Harmful to Child Nutrition and Health Outcomes? A Multicountry Observational Analysis. *Am J Trop Med Hyg*. 2016. December 19, 2016. doi:10.4269/ajtmh.16-0270.

36. Headey D, Hirvonen K. Is Exposure to Poultry Harmful to Child Nutrition? An Observational Analysis for Rural Ethiopia. *PLoS One*. Aug 2016;11(8)doi:10.1371/journal.pone.0160590.

37. Gelli A, Headey D, Becquey E, et al. Poultry husbandry, water, sanitation, and hygiene practices, and child anthropometry in rural Burkina Faso. *Maternal & child nutrition*. 2019;15(4):e12818.

38. Conan A, O'Reilly CE, Ogola E, et al. Animal-related factors associated with moderate-to-severe diarrhea in children younger than five years in western Kenya: a matched case-control study. *PLoS neglected tropical diseases*. 2017;11(8):e0005795.

39. George CM, Cirhuza LB, Kuhl J, et al. Child mouthing of feces and fomites and animal contact are associated with diarrhea and impaired growth among young children in the Democratic Republic of the Congo: a prospective cohort study (REDUCE Program). *The journal of Pediatrics*. 2021;228:110-116.

40. Medgyesi DN, Brogan JM, Sewell DK, Creve-Coeur JP, Kwong LH, Baker KK. Where Children Play: Young child exposure to environmental hazards during play in public areas in a transitioning internally displaced persons community in Haiti. *International Journal of Environmental Research and Public Health*. 2018;15(8):1646.

41. Medgyesi D, Sewell D, Senesac R, Cumming O, Mumma J, Baker KK. The landscape of enteric pathogen exposure of young children in public domains of low-income, urban Kenya: The influence of exposure pathway and spatial range of play on multi-pathogen exposure risks. *PLOS Neglected Tropical Diseases*. 2019;13(3):e0007292. doi:10.1371/journal.pntd.0007292.

42. Chen D, Mechlowitz K, Li X, Schaefer N, Havelaar AH, McKune SL. Benefits and Risks of Smallholder Livestock Production on Child Nutrition in Low- and Middle-Income Countries. *Frontiers in nutrition*. 2021;8:751686-751686. doi:10.3389/fnut.2021.751686.

43. George CM, Oldja L, Biswas SK, et al. Fecal Markers of Environmental Enteropathy are Associated with Animal Exposure and Caregiver Hygiene in Bangladesh. *Am J Trop Med Hyg*. Aug 2015;93(2):269-75. doi:10.4269/ajtmh.14-0694.

44. Alebel A, Tesema C, Temesgen B, Gebrie A, Petrucka P, Kibret GD. Prevalence and determinants of diarrhea among under-five children in Ethiopia: A systematic review and meta-analysis. *PLOS ONE*. 2018;13(6):e0199684. doi:10.1371/journal.pone.0199684.

45. Pickering AJ, Swarthout J, Mureithi M, et al. Can individual and integrated water, sanitation, and handwashing interventions reduce fecal contamination in the household environment? Evidence from the WASH Benefits cluster-randomized trial in rural Kenya. *BioRxiv*. 2019:731992.

46. Barnes AN, Anderson JD, Mumma J, Mahmud ZH, Cumming O. The association between domestic animal presence and ownership and household drinking water contamination among peri-urban communities of Kisumu, Kenya. *PloS one*. 2018;13(6):e0197587.

47. Passarelli S, Ambikapathi R, Gunaratna NS, et al. The role of chicken management practices in children's exposure to environmental contamination: a mixed-methods analysis. *BMC public health*. 2021;21(1):1-15.

48. Ngure F, Gelli A, Becquey E, et al. Exposure to livestock feces and water quality, sanitation, and hygiene (wash) conditions among caregivers and young children: Formative research in rural Burkina Faso. *The American journal of tropical medicine and hygiene*. 2019;100(4):998.

49. Pinto J C, Keestra S, Tandon P, Chandler CI. WASH and biosecurity interventions for reducing burdens of infection, antibiotic use and antimicrobial resistance in animal agricultural settings: a One Health mixed methods systematic review. 2020.

50. Vila-Guilera J, Parikh P, Chaturvedi H, Ciric L, Lakhanpaul M. Towards transformative WASH: an integrated case study exploring environmental, sociocultural, economic and institutional risk factors contributing to infant enteric infections in rural tribal India. *BMC Public Health*. 2021;21(1):1-15.

51. Delahoy MJ, Wodnik B, McAliley L, et al. Pathogens transmitted in animal feces in low- and middle-income countries. *International Journal of Hygiene and Environmental Health*. 2018/05/01/ 2018;221(4):661-676. doi:https://doi.org/10.1016/j.ijheh.2018.03.005.

52. Maleta KM, Manary MJ. WASH alone cannot prevent childhood linear growth faltering. *The Lancet Global Health*. 2019;7(1):e16-e17.

53. National Research Council. Exposure science in the 21st century: a vision and a strategy. 2012.

Chapter 6. Appendix

6.1. Research aim 2 Supporting information

Table S 1. PRISMA Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Methods
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Methods
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Methods
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Methods
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Methods
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Not assessed
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Not assessed

Section and Topic	Item #	Checklist item	Location where item is reported
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Methods
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Methods
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Methods
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Methods
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Not assessed
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Not assessed
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Not assessed
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Not assessed
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Results, Figure 2
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Not assessed
Study characteristics	17	Cite each included study and present its characteristics.	Results, Table 2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Not assessed
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Not assessed
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Not assessed
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Not assessed
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Not assessed
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Not assessed
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Not assessed
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Not assessed
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Discussion

Section and Topic	Item #	Checklist item	Location where item is reported
	23b	Discuss any limitations of the evidence included in the review.	Discussion
	23c	Discuss any limitations of the review processes used.	Discussion
	23d	Discuss implications of the results for practice, policy, and future research.	Discussion
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Methods
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Methods
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Not applicable
Competing interests	26	Declare any competing interests of review authors.	Competing interests statement
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Methods

Figure S 1. Number of studies published over time (*n*=184)

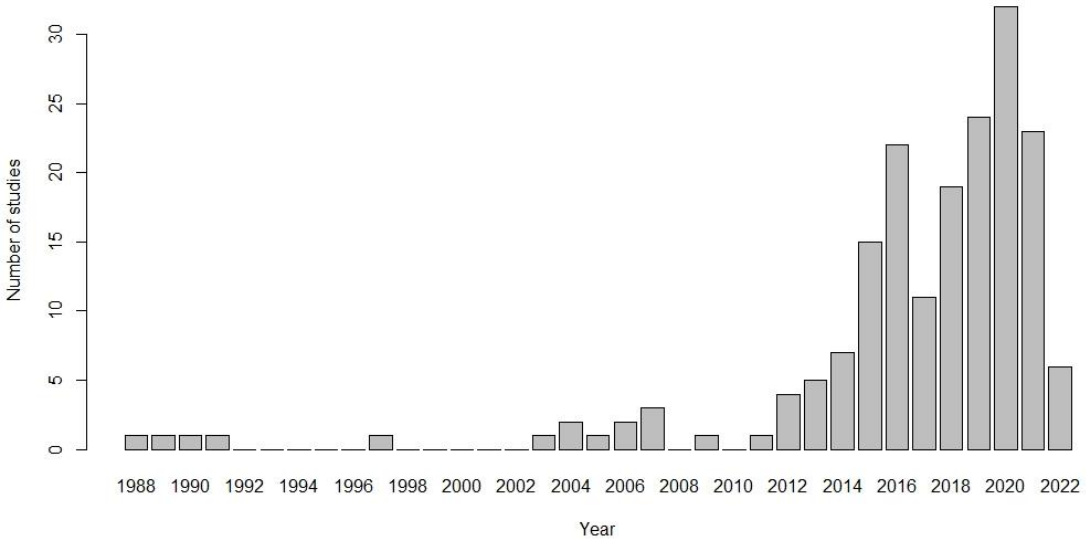


Table S 2. Characteristics of studies (*n*=184) included in review of human exposure to animal feces

Authors	Year	Location	Study design	Study aim	Study population & sample size
Abdo SM et al.	2021	Nile Delta, Egypt	Cross-sectional	Detect the prevalence and characterize Blastocystis sequence-tagged-sites in humans and cattle to investigate the potential risk of zoonotic transmission	Humans (*n*=136), cattle (*n*=190)
Abello JJM et al.	2021	Laguna Lake, Philippines	Cross-sectional	Identify sources of fecal contamination in Laguna Lake	Water samples (*n*=424)
Adjei AA et al.	2004	Accra, Ghana	Case-control	Determine the prevalence of Cryptosporidium spp. infection among children with and without diarrhea, and examine its association with transmission-related risk factors	Diarrheic children (*n*=277), control children (*n*=77)
Ajjampur SSR	2021	Tamil Nadu, India	Cross-sectional	Estimate the prevalence of soil-transmitted helminths and identify associated factors	Humans (*n*=6,089)
Alyousefi NA et al.	2011	Sana'a city, Yemen	Cross-sectional	Determine the prevalence and factors associated with intestinal protozoan infections	Humans (*n*=503)
Amar OAO et al.	2015	Allahabad, India	Cross-sectional	Determine the seroprevalence of Toxoplasma gondii infections	Pregnant women (*n*=103)
Anuar TS et al.	2012	Peninsular Malaysia	Cross-sectional	Assess the prevalence and identify underlying risk factors associated with E. histolytica/E. dispar/E. moshkovskii infection	Humans (*n*=500)
Anuar TS et al.	2014	Peninsular Malaysia	Cross-sectional	Identify Giardia duodenalis assemblage and the risk factors	Humans (*n*=611)
Awobode HO et al.	2020	Ibadan, Nigeria	Cross-sectional	Estimate the shedding proportion of T. gondii-like oocysts in cats and soil contamination levels	Soil samples (*n*=204), cat fecal samples (*n*=14), cat sera (*n*=15)
Ayinmode AB et al.	2016	Ibadan, Nigeria	Cross-sectional	Investigate the presence of gastrointestinal parasites present in dog feces in the street	Dog fecal samples (*n*=203)
Baker KK et al.	2018	Kisumu, Kenya	Cross-sectional	Characterize across- and within-neighborhood diversity in enteric pathogen contamination of public domains	Soil samples (*n*=62), surface water samples (*n*=51)
Bandaranayaka KO et al.	2019	Lunugala Tea estate, Sri Lanka	Cross-sectional	Understand the connection between health of humans, dogs, and the environment in relation to gastrointestinal parasites	Humans (*n*=50), dog fecal samples (*n*=50), soil samples (*n*=16)

Authors	Year	Location	Study design	Study aim	Study population & sample size
Barnes AN et al.	2018	Kisumu, Kenya	Cross-sectional	Assess association between household water contamination and factors related to WAS, or animals	Households (*n*=800)
Barnes AN et al.	2020	Mongolia	Cross-sectional	Identify zoonotic disease knowledge and practices among herding households	Households (*n*=150)
Barnes AN et al.	2021	Mongolia	Cross-sectional	Determine the prevalence of Cryptosporidium spp. or Giardia spp. in humans, animals, and the environment and identify associated risk factors	Households (*n*=250)
Beiromvand M et al.	2019	Shushtar County, Iran	Cross-sectional	Investigate the influence of risk factors on intestinal parasitic diseases	Humans (*n*=1,008)
Bern C et al.	2005	Lima, Peru	Cross-sectional	Evaluate the contribution of intestinal microsporidiosis to chronic diarrhea, risk factors associated with infection, and the influence of intestinal microsporidiosis on survival in HIV-positive patients	Humans (*n*=2,652)
Bernal RIR et al.	2017	Pamplona, Colombia	Cross-sectional	Determine epidemiological factors related to the anti-Toxocara canis seropositivity in children with a pet	Children (*n*=165), dog fecal samples (*n*=136)
Black RE et al.	1989	Huascar, Peru	Longitudinal	Investigate the etiology of diarrheal diseases and common routes of transmission	Infants (*n*=153), cats (*n*=13), chickens (*n*=23), dogs (*n*=4), ducks (*n*=7), goats (*n*=1), guinea pigs (*n*=4), pigs (*n*=1), pigeons (*n*=2), rabbits (*n*=7)
Boehm AB et al.	2016	Rural Bangladesh	Nested randomized control trial	Evaluate if improved sanitation to compounds reduced the incidence of a human-associated fecal genetic marker and rotavirus RNA and assess the occurrence of ruminant and avian-associated fecal genetic markers	Compounds (*n*=497)
Boyko RH et al.	2020	Kintampo North Municipality, Ghana	Retrospective study and prospective field study	Investigate the link between exposure to dog feces and hookworm infection status	Children (*n*=812), child sera samples (*n*=89), dog fecal samples (*n*=64), pig fecal samples (*n*=20)

Authors	Year	Location	Study design	Study aim	Study population & sample size
Bublitz DC et al.	2014	Ranomafana National Park, Madagascar	Cross-sectional	Examine patterns of infection in humans, livestock, and peridomestic rodents, and behaviors associated with infection	Humans (*n*=163), cattle (*n*=58), pigs (*n*=18), rodents (*n*=65)
Budge S et al.	2019	Sidama zone, Ethiopia	Cross-sectional	Assess how the presence of animals within the household, household sanitation and key hygiene practices affect levels of thermotolerant coliform bacterial contamination	Children (*n*=20)
Budge S et al.	2020	Sidama zone, Ethiopia	Cross-sectional	Understand relationships between infant Campylobacter prevalence, malnutrition and associated risk factors	Households (*n*=35), poultry fecal samples (*n*=35)
Budge S et al.	2021	Sidama zone, Ethiopia	Randomized controlled trial	Assess the feasibility of a playspace intervention	Intervention households (*n*=50), control households (*n*=50)
Budiono NG et al.	2019	Lindu Subdistrict, Indonesia	Cross-sectional	Determine the prevalence of and identify the risk factors associated with, Schistosoma japonicum infection in animals, and identify animals' relative contributions to S. japonicum transmission	Buffalo fecal samples (*n*=26), cattle fecal samples (*n*=13), dog fecal samples (*n*=8), horse fecal samples (*n*=28), pig fecal samples (*n*=59)
Bukenya GB et al.	1991	Kilakila settlement, Papua New Guinea	Cohort	Identify etiological factors of childhood diarrhea	Children (*n*=479)
Cabral Monica TC et al.	2021	Jataizinho, Brazil	Cross-sectional	Evaluate the seroprevalence and risk factors associated with toxoplasmosis and toxocariasis in schoolchildren	Children (*n*=412)
Capone D et al.	2019	Maputo, Mozambique	Cross-sectional	Assess the relationship between localized fecal hazards, sanitary conditions, and other key variables	Compounds (*n*=80)
Caron Y et al.	2018	Kratie and Ratanak Kiri, Cambodia	Cross-sectional	Explore associations between exposure of young children to animal feces and nutritional status	Children (*n*=639)

Authors	Year	Location	Study design	Study aim	Study population & sample size
Chard AN et al.	2020	Saravane Province, Lao People's Democratic Republic	Cross-sectional	Estimate the prevalence of enteropathogens among children <5, school-aged children, and adults and assess associations between WASH transmission pathways and enteropathogen infections	Households (*n*=297), school-aged children (*n*=297), children <5 years (*n*=297), adults (*n*=297)
Chavez-Lindell TL et al.	2022	Chimborazo, Ecuador	Cross-sectional	Explore animal and waste management practices and identify predictors of diarrheal illness among children and adults	Households (*n*=58)
Chiodo P et al.	2006	General Mansilla, Argentina	Cross-sectional	Evaluate the relationship between toxocariasis prevalence and risk factors and other intestinal parasites	Humans (*n*=100), dogs (*n*=81), household soil samples (*n*=47), public park soil samples (*n*=4)
Chuma IS et al.	2016	Morogoro Municipality, Tanzania	Cross-sectional	Determine the prevalence, risk factors and genetic diversity of thermophilic Campylobacter isolates from children and chickens	Children (*n*=268), chicken fecal samples (*n*=419)
Cociancic P et al.	2020	Ushuaia, Argentina	Cross-sectional	Determine the presence, diversity, and shedding potential of intestinal parasites in dog feces contaminating the environment	Dog fecal samples (*n*=80)
Coello-Peralta R et al.	2019	Milagros, Ecuador	Cross-sectional	Determine the presence of Hymenolepis nana and diminuta in rodents	Humans (*n*=90), rodents (*n*=87)
Collinet-Adler S et al.	2015	Vellore, India	Cohort	Examine the link between fly densities and diarrheal outcomes at the household level	Humans (*n*=1,274)
Conan A et al.	2017	Siaya County, Kenya	Matched case-control	Identify animal-related exposures associated with diarrhea cases in children, and identify the zoonotic enteric pathogens present in domestic animals	Diarrheic case children (*n*=73), control children (*n*=73)
Contreras JD et al.	2021	Bangladesh	Nested randomized controlled trial	Investigate the environmental impacts of a WASH RCT	Households (*n*=720)

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Cumberland P et al.	2004	Gurage, Oromia, and South Welo, Ethiopia	Cross-sectional	Evaluate the effect of a prevention and treatment program on the prevalence of active trachoma	Children (*n*=1,960)
Cvetkova T et al.	2018	Varna City, Bulgaria	Cross-sectional	Investigate the environmental contamination with Toxocara spp. eggs of soil and sand samples of several public places	Soil samples (*n*=34), sand samples (*n*=6)
Da Silva DTG et al.	2020	Asembo, Kenya	Cross-sectional	Investigate the association between domestic contact with livestock and the microbial contamination of household stored water	Households (*n*=234)
Da Silva NMM et al.	2019	Garanhuns, Brazil	Longitudinal	Evaluate the presence of immature forms of gastrointestinal parasites of mammals in soil	Soil samples (*n*=211)
Dang-Xuan S et al.	2017	Chi Linh district, Vietnam	Cross-sectional	Determine the association of coughing, fever, and diarrhea/nausea/vomiting with livestock ownership, livestock husbandry practices, and livestock waste exposures	Humans (*n*=5,520)
Daniels ME et al.	2015	Odisha, India	Cross-sectional	Assess the relevance of Cryptosporidium and Giardia for local disease burdens and the potential for zoonotic transmission from animals	Humans (*n*=85), animals (*n*=111)
Daniels ME et al.	2016	Odisha, India	Conceptual model	Investigate the potential causes of previously reported Cryptosporidium and Giardia contamination	Community ponds (*n*=94), deep tube wells (*n*=107), shallow tube wells (*n*=96)
Das R et al.	2022	The Gambia, Kenya, Mali, Mozambique, Bangladesh, India, Pakistan	Prospective case-control	Compare and differentiate between factors of NTS infection among children of two distinctly different geographic regions	Children (*n*=1,512)
de Bruyn J et al.	2018	Manyoni District, Tanzania	Longitudinal	Understand how domestic animal ownership nfluences children's nutrition and health	Children (*n*=503)

Authors	Year	Location	Study design	Study aim	Study population & sample size
de Macedo LO et al.	2019	Pernambuco, Brazil	Cross-sectional	Detect gastrointestinal parasites in dog's feces collected in households, streets and public squares	Dog fecal samples (*n*=640)
Delai RR et al.	2021	Paraná, Brazil	Cross-sectional	Assess the seroprevalence of anti-Toxocara antibodies in traditional human seashore populations	Humans (*n*=328), dog fecal samples (*n*=115), cat fecal samples (*n*=15), dog hair samples (*n*=104), environmental samples (*n*=130)
Dorjsuren T et al.	2020	Mongolia	Cross-sectional	Investigate the prevalence of cystic echinococcosis and its potential risk factors	Humans (*n*=1,381)
Dwivedi KK et al.	2007	Delhi, India	Case-control	Measure enteric parasites prevalence and associated factors and CD4+ T-lymphocyte counts in HIV infected individuals	Diarrheic individuals (*n*=75), control (*n*=25)
Eisen AKA et al.	2019	Novo Hamburo, Brazil	Cross-sectional	Evaluate the presence of Canine mastadenovirus A, Carnivore protoparvovirus 1, different species of Mastadenovirus from mammals	Soil samples (*n*=216), dog fecal samples (*n*=16)
El-Tras WF et al.	2015	Gharbia, Egypt	Cross-sectional	Investigate whether children exposed to Campylobacter-infected poultry were at higher risk of being infected by Campylobacter	Children (*n*=106), poultry (*n*=379)
Ercumen A et al.	2017	Bangladesh	Cross-sectional	Characterize fecal contamination along environmental transmission pathways and determine how the presence of animals, sanitary infrastructure, and ambient climate conditions affect contamination levels	Mother-child dyads (*n*=608)
Ercumen A et al.	2018	Bangladesh	Nested randomized control trial	Assess how sanitation improvements, alone and combined with water and handwashing interventions, affect fecal contamination along	Mother-child dyads (*n*=1,840)

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Ercumen A et al.	2020	Kiryandongo and Masindi, Uganda	Cross-sectional	Assess the relationship between ownership of domestic animals and diarrhea and respiratory infection in children	Children (*n*=1,336)
Erismann S et al.	2016	Plateau Central and Centre-Ouest regions, Burkina Faso	Cross-sectional	Assess the prevalence and risk factors of intestinal parasitic infections in school-aged children	Children (*n*=385)
Fang EE et al.	2021	Bamenda Health District, Cameroon	Cross-sectional	Determine the seroprevalence of Toxoplasma gondii infection in HIV positive patients and associated risk factors	Humans (*n*=325)
Fernando SD et al.	2017	Colombo, Sri Lanka	Cross-sectional	Investigate the relationship between Toxocara seropositivity, socio-demographic and environmental variables	Children (*n*=196)
Fuhrmeister ER et al.	2020	Bangledesh	Randomize control trial	Quantify the impact of a sanitation intervention (a combined human and animal fecal management intervention that included dual-pit latrines, sani-scoops, and child potties) on enteric pathogen genes and indicators in household environmental reservoirs	Intervention households (*n*=300), control households (*n*=300), stored drinking water samples (*n*=720), soil samples (*n*=720), maternal hand rinses (*n*=720), child hand rinses (*n*=360)
Gawad SSA et al.	2018	Beni-Suef, Egypt	Cross-sectional	Document the occurrence of C. parvum among individuals having diarrhea and associated factors	Diarrheic patients (*n*=200)
Gboko KDT et al.	2019	Korhogo, Cote d'Ivoire	Cross-sectional	Identify risk factors for Streptococcus infantarius subsp. Infantarius fecal carriage corresponding with consumption of local dairy products	Adults (*n*=385)
Gebrewahd A et al.	2020	Tigrai, Ethiopia	Cross-sectional	Assess the bacteriological quality and associated risk factors of drinking water	Water sources (*n*=290)

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Geda N et al.	2019	Oromia, Ethiopia	Cross-sectional	Determine the prevalence and associated risk factors of Cryptococcal antigenemia among HIV/AIDS patients	Human (*n*=183)
Gelli A et al.	2019	Rural Burkina Faso	Cross-sectional	Understand if WASH characteristics and/or the presence of poultry feces associated with anthropometric indices in young children	Children (*n*=3,230)
George CM et al.	2015	Mirzapur upazila, Bangladesh	Cross-sectional	Determine if household level sanitary environmental conditions are associated with EED and stunting in children	Children (*n*=216)
George CM et al.	2021	South Kivu, Democratic Republic of the Congo	Prospective cohort	Investigate the association between child behaviors, the presence of animals, and diarrheal disease and impaired growth	Children (*n*=370)
Getaneh DK et al.	2021	Eastern Ethiopia	Cross-sectional	Determine the prevalence of E. coli O157: H7 and its associated factors among children	Children (*n*=365)
Gharieb RMA et al.	2018	Sharkia Province, Egypt	Cross-sectional	Determine the prevalence of Cryptosporidium spp. in household dogs and in-contact children, and risk factors associated with infection in children	Children (*n*=100), dogs (*n*=50)
Gizaw et al.	2022	Dembiya district, Ethiopia	Cross-sectional	Assess environmental exposures of children to intestinal parasites	Children (*n*=372)
Glagn MA et al.	2020	Arba Minch, Ethiopia	Cross-sectional	Assess the prevalence of active trachoma and the factors associated with it	Children (*n*=831)
Goes GC et al.	2019	Niterói, Brazil	Cross-sectional	Evaluate the frequency of intestinal parasitosis in children enrolled in public daycare centers	Children (*n*=121)
Grados O et al.	1988	Lima, Peru	Case-control	Identify risk factors and possible means of transmission of campylobacter in children	Diarrheic children (*n*=104), controls (*n*=104)
Gurler AT et al.	2020	Samsun, Turkey	Cross-sectional	Ascertain the relationship between cat and/or dog feces and the contamination of sand playgrounds with Toxocara spp. eggs in public parks	Sand samples (*n*=596), dog fecal samples (*n*=148), cat fecal samples (*n*=128)

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Harris AR et al.	2016	Dhaka, Bangladesh	Cross-sectional	Understand fecal contamination using microbial source tracking and fecal indicator bacterial assays	Households (*n*=59)
Harvey SA et al.	2003	Las Pampas de San Juan de Miraflores, Peru	Cross-sectional	Explore the feasibility of corralling poultry and assess use and efficacy of corrals in reducing C. jejuni-related infections	Families for corralling practices (*n*=62), people for perceptions of poultry (*n*=50), people in semi-structured interviews (*n*=15), avian fecal samples (*n*=1,711)
Headey D et al.	2016	Ethiopia	Cross-sectional	Test the hypothesis that poultry ownership in Ethiopia has both a positive association and a negative association with child health	Children (*n*=3,494)
Headey D et al.	2017	Bangladesh, Ethiopia, Vietnam	Cross-sectional	Investigate if the presence of animal feces is significantly associated with child growth and morbidity	Mother-child dyads (*n*=6,068)
Holcomb DA et al.	2020	Maputo, Mozambique	Cross-sectional	Investigate the sources and patterns of fecal contamination and assess risk factors of fecal contamination in multiple domestic transmission pathways	Environmental samples (*n*=366), households (*n*=94), compounds (*n*=58)
Holcomb DA et al.	2021	Maputo, Mozambique	Non-randomized controlled trial	Determine the impacts of an urban sanitation intervention of fecal indicators	Environmental samples (*n*=770), compounds (*n*=71)
Huda TMN et al.	2019	Bangladesh	Cross-sectional	Assess the association between neighborhood sanitation coverage and contamination of the household environment	Households (*n*=428)
Iwashita H et al.	2020	Hien Khanh, Vietnam	Cohort	Determine the genetic diversity of Giardia spp. In both humans and livestock to assess the existence of a route of infection between livestock and humans	Humans (*n*=1,508), buffalo fecal samples (*n*=17), cow fecal samples (*n*=74), dog fecal samples (*n*=3), pig fecal samples (*n*=28), monkey fecal samples (*n*=1), wild boar fecal samples (*n*=1)

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Iwashita H et al.	2021	Hien Khanh, Vietnam	Cohort	Investigate the occurrence of Cryptosporidium infections and the potential for transmission of Cryptosporidium spp. between animals and humans	Humans (*n*=1,508), buffalo fecal samples (*n*=17), cattle fecal samples (*n*=74), dog fecal samples (*n*=3), pig fecal samples (*n*=28), monkey fecal samples (*n*=1), wild boar fecal samples (*n*=1)
Jeske S et al.	2018	Pelotas, Brazil	Cross-sectional	Evaluate the frequency of intestinal parasites in cancer patients	Cancer patients (*n*=73)
Kamau J et al.	2021	Laikipia County, Kenya	Cross-sectional	Assess the relationship between specific behaviors and self-reported illnesses	Humans (*n*=327)
Kashinahanji M et al.	2019	Hamadan, Iran	Cross-sectional	Assess the prevalence of G. lamblia assemblages and their possible relationship with clinical symptoms of the patients	Humans (*n*=4,066)
Kaur M et al.	2017	Sub-Saharan Africa	Cross-sectional	Investigate the association between child health and household ownership of livestock	Children (*n*=215,996)
Khan W et al.	2020	Dir district, Pakistan	Cross-sectional	Assess gastrointestinal parasites in stray dogs and household dogs	Stray dog fecal samples (*n*=90), household dog fecal samples (*n*=62)
Kladkempetch D et al.	2020	Thailand	Cross-sectional	Identify species of hookworm in dogs and the presence of hookworm contamination near community temples	Dog fecal samples (*n*=299), soil samples (*n*=16)
Labrique AB et al.	2013	Rural Bangladesh	Case-control	Identify putative risk factors for Hepatitis E	HEV cases (*n*=46), controls (*n*=134)
Lambrecht NJ et al.	2021	Accra, Ghana	Cross-sectional	Determine the association between livestock ownership, exposure to livestock feces, animal-source food consumption, and enteric infections among children	Children (*n*=259)

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Laoraksawong P et al.	2020	Nakhon Si Thammarat, Thailand	Cross-sectional	Determine the prevalence of soil-transmitted helminth infections and underlying risk factors among school children	Children (*n*=192)
Leung DT et al.	2013	Dhaka, Bangladesh	Case-control	Identify risk factors and clinical features specific to patients with non-typhoidal Salmonella	Cases with non-typhoidal Salmonella in stool (*n*=486), controls (*n*=762)
Li N et al.	2019	Ibadan, Nigeria	Cross-sectional	Examine the occurrence and identity of Cryptosporidium spp, G. duodenalis, and E. bieneusi in straw-colored fruit bats in a popular public park	Bat fecal samples (*n*=109)
Li X et al.	2015	Henan Province, China	Cross-sectional	Evaluate risk factors of intestinal protozoan infection and intestinal helminth infection among patients with pulmonary tuberculosis	Humans (*n*=389)
Lowenstein C et al.	2020	Yaruqui, Ecuador	Cross-sectional	Test the hypothesis that domestic animal ownership is associated with carriage of one or more zoonotic enteric pathogens by children and diarrhea at the household-level	Children (*n*=306), dog fecal samples (*n*=134), chicken fecal samples (*n*=102), guinea pig fecal samples (*n*=84), pig fecal samples (*n*=62), rabbit fecal samples (*n*=39), cat fecal samples (*n*=21), cow fecal samples (*n*=21), duck fecal samples (*n*=17)
Lupindu AM et al.	2014	Morogoro, Tanzania	Cross-sectional	Estimate the prevalence of NSF STEC O157:H7 and other NSF E. coli in cattle, humans, and the associated environment	Humans (*n*=200), cow fecal samples (*n*=446)
Macchioni F et al.	2016	Chaco region, Bolivia	Cross-sectional	Determine the prevalence and risk factors of intestinal parasite infections in children and the adult population	Humans (*n*=223)
Maciel MG et al.	2018	Canutama, Brazil	Cross-sectional	Describe the transmission of human fascioliasis	Humans (*n*=434)

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Makala R et al.	2020	Ngorongoro district, Tanzania	Cross-sectional	Investigate the seroprevalence and factors associated with Brucella infection among pregnant women	Pregnant women (*n*=313)
Malla B et al.	2018	Kathmandu Valley, Nepal	Cross-sectional	Validate host-specific Bacteroidales assays to identify fecal-source contamination of drinking water sources	Drinking water samples (*n*=74)
Malla B et al.	2019	Kathmandu Valley, Nepal	Cross-sectional	Determine the potential distribution of fecal contamination in different groundwater sources	Drinking water samples (*n*=300)
Marquis GS et al.	1990	Lima, Peru	Cross-sectional	Measure the rate at which toddlers in shanty town contaminate themselves with domestic poultry feces	Children (*n*=10)
Mazhab-Jafari K et al.	2019	Khorramshahr, Iran	Cross-sectional	Determine the presence of Toxocara spp. eggs at parks and green public areas	Soil samples (*n*=150)
Mbae C et al.	2020	Mukuru, Kenya	Cross-sectional	Determine the incidence, spatial distribution, socioeconomic and environmental risk factors for Salmonella infections	Children (*n*=16,236)
Medgyesi DN et al.	2018	Corail, Haiti	Cross-sectional	Measure the rate at which children practice behaviors such as hand and mouth contacts with objects that could lead to illness and injury	Children (*n*=386)
Medina-Pinto R et al.	2018	Merida, Mexico	Cross-sectional	Estimate the frequency of the presence of intestinal nematodes in dog feces in parks and determine associated factors	Dog fecal samples (*n*=100)
Mello CCS et al.	2020	Rio Grande do Sul, Brazil	Cross-sectional	Evaluate environmental contamination by zoonotic agents in dog feces collected close to elementary schools	Dog fecal samples (*n*=79)
Mohammad SM et al.	2021	Sharkyia, Egypt	Cross-sectional	Detect the Cryptosporidium genotypes that infect children suffering from diarrhea	Children (*n*=97)
Molbak K et al.	1997	Bandim II, Guinea-Bissau	Community-based cohort	Examine a range of possible risk factors for diarrheal diseases	Children (*n*=1,314)
Monira S et al.	2020	Dhaka, Bangladesh	Prospective cohort	Investigate potential risk factors for growth faltering among children	Children (*n*=553)

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Moore CE et al.	2016	Siem Reap, Cambodia	Cross-sectional	Asses the occurrence and associated risk factors of child Cryptosporidium spp. and Giardia duodenalis infection	Children (*n*=498)
Mosites E et al.	2016	Western Kenya	Prospective cohort	Evaluate relationships between household livestock ownership, episodes of livestock disease, and child growth trajectory	Children (*n*=925)
Mpyet C et al.	2012	Kano State, Nigeria	Cross-sectional	Estimate the magnitude of trachoma and the risk factors for disease	Humans (*n*=4,491)
Muadica AS et al.	2021	Zambezia province, Mozambique	Cross-sectional	Assess potential risk/protective factors of enteric parasite infections in symptomatic and asymptomatic children	Children (*n*=1,093)
Nasr NA et al.	2020	Peninsular Malaysia	Cross-sectional	Investigate the prevalence, distribution and risk factors of soil-transmitted helminth infections	Children (*n*=1,142)
Navab-Daneshmand T et al.	2018	Harare, Zimbabwe	Cross-sectional	Identify risk factors for E. coli contamination in drinking and handwashing water, soil, and hands	Households (*n*=142)
Ngui R et al.	2020	Peninsular Malaysia	Cross-sectional	Determine the prevalence and risk factors of Entamoeba infection in humans and dogs	Humans (*n*=411), dog fecal samples (*n*=93)
Ngure FM et al.	2013	Midlands Province, Zimbabwe	Cross-sectional	Identify pathways of fecal-oral transmission of bacteria among infants	Caregiver-child dyads (*n*=23), chicken fecal samples (*n*=42), kitchen floor samples (*n*=42)
Ngure F et al.	2019	Rural Burkina Faso	Cross-sectional	Assess the exposure of livestock feces and WASH conditions among caregivers and young children at household level	Caregiver-child dyads (*n*=20)
Nigusie A et al.	2015	Gonji kolella district, Ethiopia	Cross-sectional	Determine the prevalence of active trachoma and associated factors	Children (*n*=618)
Oberhelman RA et al.	2006	Las Pampas de San Juan de Miraflores, Peru	Longitudinal	Assess if corralling free-ranging chickens would decrease rates of Campylobacter infections and diarrhea in children exposed to chickens	Households (*n*=62), samples from chickens and humans (*n*=8,216)

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Odagiri M et al.	2016	Odisha, India	Cross-sectional	Measure prevalence of human and animal fecal contamination and examine the effect of increased latrine coverage	Households (*n*=354), community tubewells and ponds (*n*=301)
Okoh AEJ et al.	2017	Makurdi, Nigeria	Cross-sectional	Determine the prevalence of Toxocara canis eggs in soil from public parks and play grounds	Soil samples (*n*=816)
Ordiz MI et al.	2016	Rural Malawi	Cross-sectional	Assess gut health in rural Malawian children	Children (*n*=798)
Osbjer K et al.	2015	Cambodia	Cross-sectional	Identify practices that influence zoonosis transmission and what factors are related	Households (*n*=300)
Parvez SM et al.	2017	Bangladesh	Cross-sectional	Assess the frequency and concentration of E. coli contamination and related environmental and behavioural factors	Households (*n*=720)
Parvez SM et al.	2019	Bangladesh	Cross-sectional	Identify the prevalence and concentration of E. coli in child hand rinse samples and determine how well observed hand cleanliness serves as a potential proxy	Households (*n*=584)
Peña-Quistial MG et al.	2020	Valle del Cauca, Colombia	Cross-sectional	Determine the prevalence of parasites in domestic animals and children populations	Children (*n*=50), animal fecal samples (*n*=64)
Pereira MDGC et al.	2007	Goias, Brazil	Cross-sectional	Determine prevalence of giardiasis and identify risk factors associated with infection	Diarrheic children (*n*=445)
Prasetyo RH	2019	East Java, Indonesia	Cross-sectional	Investigate the prevalence of two zoonotic intestinal parasites in house rats from slum areas	House rat fecal samples (*n*=100)
Quadros RM et al.	2016	Lages, Brazil	Cross-sectional	Explore conditions that impact the prevalence of zoonotic features of G. duodenalis	Children (*n*=91), dog fecal samples (*n*=108)
Raicevic JG et al.	2021	Krusevac, Serbia	Cross-sectional	Detect presence of intestinal parasites in canine feces in public areas	Dog fecal samples (*n*=282)
Randremanana na RV et al.	2016	Madagascar	Case-control	Understand the etiology, risk factors, and effects on nutritional status of severe diarrhea	Diarrheic children (*n*=199), controls (*n*=199)

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Rebih N et al.	2020	Djelfa, Algeria	Cross-sectional	Estimate the prevalence of G. intestinalis assemblages to understand genetic diversity and transmission	Children (*n*=355)
Reichert F et al.	2016	Manaus, Brazil	Cross-sectional	Determine the prevalence of hookworm-related Cutaneous Larva Migrans and risk factors	Humans (*n*=806)
Reid B et al.	2018	Lundazi District, Zambia	Cross-sectional	Observe potential fecal-oral pathways or microbial transmission among infant and young children	Mother-child dyads (*n*=30)
Ribas A et al.	2016	Udon Thani, Thailand	Cross-sectional	Understand the role of rodents as reservoirs of zoonotic helminthiases in traditional wet markets	Rats (*n*=98)
Rivero M et al.	2013	Buenos Aires	Retrospective longitudinal study	Describe the hemolytic uremic syndrome (HSU) cases from 2005-2010 and characterize the differential distribution of the factors associated with cases	HSU patients (*n*=64)
Rivero MR et al.	2017	Iguazu, Argentina	Cross-sectional	Examine the prevalence of enteroparasites and parasite environmental contamination and explore related environmental and socio-demographic characteristics	Children (*n*=483), dog fecal samples (*n*=530)
Ruang-areerate T et al.	2017	Thakradan, Thailand	Cross-sectional	Examine potential sources of Blastocystis transmission among people in agricultural communities	Humans (*n*=902)
Saaed FMA et al.	2019	Kufra City, Libya	Case-control	Determine the occurrence of Cryptosporidium and Giardia among children with diarrhea	Diarrheic case children (*n*=505), control children (*n*=100)
Sack A et al.	2018	Mongolia	Cross-sectional	Describe potential risk factors for zoonotic disease transmission	Households (*n*=131)
Sack A et al.	2021	Tamil, India	Cross-sectional	Investigate associations among contaminated household soil, infected domestic animals, and human risk factors	Humans (*n*=428)
Samra NA et al.	2016	Kruger National Park, South Africa	Cross-sectional	Estimate the prevalence of Cryptosporidium spp. and identify potential risk factors associated with cryptosporidiosis in young children and calves	Children under 5 years (*n*=143), cattle (*n*=352)

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Sardarian K et al.	2015	Hamadan, Iran	Cross-sectional	Assess the prevalence of intestinal parasites in stray and household dogs	Household dog fecal sample (*n*=1,500), stray dog fecal samples (*n*=1257)
Sazzad HMS et al.	2017	Dhaka, Bangladesh	Case-control	Identify the risk factors for sporadic hepatitis E (HEV) and the causative genotype(s)	HEV cases (*n*=109), controls (*n*=109)
Schiaffino F et al.	2021	Loreto, Peru	Cross-sectional	Assess the associations between presence of animal feces and other characteristics	Households (*n*=104)
Schmidt WP et al.	2015	Odisha, India	Cohort	Assess the relationship between cow exposure, diarrhea, flies, and child growth	Children (*n*=2,739)
Schriewer A et al.	2015	Puri District, India	Cross-sectional	Assess pathways and risks of exposure to fecal pathogens in public and domestic domains	Households (*n*=137), community water sources (*n*=123)
Schurer JM et al.	2019	Maha Sarakham Province, Thailand	Cross-sectional	Characterize the prevalence and intensity of gastrointestinal parasites in people and long-tailed macaques with overlapping living space	Humans (*n*=115), macaques (*n*=102)
Shehab AY et al.	2020	Gharbia governorate, Egypt	Cross-sectional	Study the prevalence of intestinal parasitic infections among humans and their contact livestock animals	Humans (*n*=300), livestock animals (*n*=165)
Shrestha A et al.	2020	Karnali province, Nepal	Cross-sectional	Assess the influence of nutrition practices and WASH infrastructure on the nutritional and health status of children	Children (*n*=1,427)
Skhal D et al.	2017	Damascus, Syria	Cross-sectional	Evaluate the predominance of G. duodenalis assemblages/sub-assemblages causing humans infection	Humans (*n*=40)
Soboksa NE	2022	Jimma Zone, Ethiopia	Cross-sectional	Determine the prevalence and factors associated with post-defecation soap hand washing practices among households	Mothers (*n*=756)

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Spencer LA et al.	2020	Tsinjoarivo, Madagascar	Cross-sectional	Measure the prevalence of Cryptosporidium sp. and Giardia sp. in sympatric lemurs, humans, domestic animals and commensal rat and assess risk factors for infection	Humans (*n*=49), black rat fecal samples (*n*=40), domestic cattle/zebu fecal samples (*n*=41), pig fecal samples (*n*=40), dog fecal samples (*n*=41), diademed sifaka fecal samples (*n*=43), eastern bamboo lemur fecal samples (*n*=44)
Sprenger LK et al.	2014	Curitiba, Brazil	Cross-sectional	Investigate the frequency of geohelminth contamination of public parks and squares	Soil/sand samples (*n*=345)
Subrata IM et al.	2015	Bali	Case-control	Assess the prevalence of toxoplasmosis and to detect T. gondii oocysts in cat feces molecularly	T. gondii-positive case mothers (*n*=40), controls (*n*=40), cat fecal samples (*n*=80)
Suwannarong K et al.	2015	Khon Kaen Province, Thailand	Cross-sectional	Understand which factors are associated with rodent-human contact	Humans (*n*=201)
Tanabe MB et al.	2022	Anta province of Cusco, Peru	Cross-sectional	Determine the geospatial relationships between Fasciola eggs passed in feces and the risk of infection among households	Children (*n*=2,070)
Thiem VD et al.	2012	Khanh Hoa, Vietnam	Population-based cohort	Investigate the association between environmental exposure to livestock and incidence of diarrhea among children	Children (*n*=33,660)
Torondel B et al.	2015	Rural India	Cross-sectional	Determine whether there is a difference in bacteria retention on different types of toy balls and which techniques achieve the highest yields	Households (*n*=326), assays (*n*=60)
Tun S et al.	2015	Klang Valley, Malaysia	Cross-sectional	Determine the prevalence of helminth eggs in animal feces and in soil samples in public areas	Cat fecal samples (*n*=152), dog fecal samples (*n*=227), soil samples (*n*=126)

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Uga S et al.	2009	Hanoi, Vietnam	Cross-sectional	Investigate vegetable contamination with parasite eggs	Vegetables (*n*=317)
Utaaker KS et al.	2018	Chandigarh, India	Cross-sectional	Determine the occurrence of gastrointestinal parasites and their seasonal variation in canine fecal samples obtained from parks	Dog fecal samples (*n*=212)
Vasco K et al.	2016	Oton de Velez-Yaruqui, Ecuador	Cross-sectional	Investigate the prevalence of 7 zoonotic enteropathogens in children and domestic animals	Children (*n*=64), cat fecal samples (*n*=6), cattle fecal samples (*n*=7), chicken fecal samples (*n*=42), dog fecal samples (*n*=40), duck fecal samples (*n*=5), goose fecal samples (*n*=1), guinea pig fecal samples (*n*=40), horse fecal samples (*n*=1), pig fecal samples (*n*=36), quail fecal samples (*n*=3), rabbit fecal samples (*n*=20), sheep fecal samples (*n*=2)
Verdeja M et al.	2019	Tanzania	Cross-sectional	Explore associations between WASH practices and self-reported childhood illness	Children (*n*=5,000)
Vila-Guilera J et al.	2021	Banswara, India	Cross-sectional	Perform a holistic exploration of the environmental, socio-cultural, economic and institutional context surrounding infant enteric infection	Children (*n*=47)
Vujcic J et al.	2014	Northern Bangladesh	Cross-sectional	Evaluate household fecal contamination using children's toys among households	Households (*n*=100)
Walteros-Casas HA et al.	2021	Villavicencio, Colombia	Cross-sectional	Determine the presence of internal and external parasites in common pigeons in public areas	Pigeons (*n*=72)

Authors	Year	Location	Study design	Study aim	Study population & sample size
Wanyiri JW et al.	2014	Nairobi, Kenya	Cross-sectional	Describe the epidemiological and clinical features of Cryptosporidium spp. infection in HIV/AIDS patients with and without diarrhea	Humans (*n*=167)
Wegayehu T et al.	2013	Oromia Region, Ethiopia	Cross-sectional	Determine the prevalence of G. duodenalis and Cryptosporidium species infection in children and cattle, and assess the risk of zoonotic transmission	Children (*n*=384), cattle fecal samples (*n*=384)
Wickramasinghe H et al.	2020	Sri Lanka	Cross-sectional	Determine the prevalence, related risk factors of canine intestinal parasitic infections, and the degree of soil contamination with Toxocara ova	Dog fecal samples (*n*=188), soil samples (*n*=139)
Wolde A et al.	2021	Wolaita Sodo Town, Ethiopia	Cross-sectional	Estimate the prevalence of E. coli and its associated risk factors among under-five children who were hospitalized	Diarrhea children (*n*=110)
Wolking DJ et al.	2016	Ruaha ecosystem, Tanzania	Cross-sectional	Identify the prevalence and risk factors for diarrheal disease and shedding of the zoonotic pathogens Cryptosporidium and Giardia	Households (*n*=159), calves (*n*=312)
Wumba R et al.	2012	Kinshasa, Democratic Republic of the Congo	Cross-sectional	Determine the prevalence of intestinal parasites and their association with HIV symptoms, risk factors, and other digestive parasites	Humans (*n*=242)
Yahaya R et al.	2018	Dutse, Nigeria	Prospective cohort	Determine the prevalence of Cryptosporidium species and G. intestinalis infections among hospital patients	Patients (*n*=120)
Yoshikawa H et al.	2016	Sumba Island, Indonesia	Cross-sectional	Understand the distributions of Blastocystis subtypes in humans and associated animals	Children (*n*=492), chickens (*n*=38), pigs (*n*=93), wild rodents (*n*=77)
Zain SNM et al.	2015	Peninsular Malaysia	Cross-sectional	Assess soil contaminated with helminths in public playgrounds	Soil samples (*n*=60)
Zamora-Velez A et al.	2020	Quindio, Colombia	Cross-sectional	Determine the prevalence of T. gondii DNA in at fecal samples	Cat fecal samples (*n*=140)

Authors	Year	Location	Study design	Study aim	Study population & sample size
Zanaj V et al.	2016	Tirana, Albania	Cross-sectional	Assess the prevalence of stray dog infestation and the level of public facility contamination from their eggs and larvae	Dog fecal samples (*n*=240)
Zonta ML et al.	2016	Pereyra Iraola Park, Argentina	Cross-sectional	Assess the sanitary conditions in the Pereyra Iraola Park and their impact on human health	Humans (*n*=80), dog fecal samples (*n*=8), farm animals (*n*=12)
Zonta ML et al.	2019	Clorinda Formosa, Argentina	Cross-sectional	Evaluate intestinal parasitosis, undernutrition, and socio-environmental factors in school children	Children (*n*=114)

Table S 3. Summary information about types of animals

	Number of studies (*n*=184) *n (%)*[a]	**Number of measures (*n*=1,428)** *n (%)*[a]
Avian species	6 (3)	21 (1)
Bats	1 (<1)	3 (<1)
Buffalo	10 (5)	18 (1)
Camel	3 (2)	7 (<1)
Cats	50 (27)	143 (10)
Cattle	65 (35)	194 (14)
Chickens	45 (24)	149 (10)
Crow	1 (<1)	1 (<1)
Diademed Sifaka	1 (<1)	2 (<1)
Dogs	79 (43)	359 (25)
Donkeys	4 (2)	23 (2)
Dove	1 (<1)	3 (<1)
Ducks	20 (11)	66 (5)
Fish	1 (<1)	2 (<1)
Fowl	5 (3)	12 (1)
Geese	2 (1)	5 (<1)
Goats	43 (23)	119 (8)
Guinea pigs	5 (3)	20 (1)
Honeybees	1 (<1)	2 (<1)
Horses	11 (6)	25 (2)
Lemur	1 (<1)	3 (<1)
Livestock	3 (2)	4 (<1)
Macaques	1 (<1)	5 (<1)
Marmot	1 (<1)	2 (<1)
Monkeys	2 (1)	2 (<1)
Pack animals	1 (<1)	4 (<1)
Parrots	1 (<1)	2 (<1)
Pigeons	7 (4)	15 (1)
Pigs	39 (21)	105 (7)
Poultry	19 (10)	57 (4)
Quail	3 (2)	7 (<1)
Rabbits	6 (3)	22 (2)
Rats or rodents	13 (7)	45 (3)
Ruminant species	8 (4)	38 (3)
Sheep	30 (16)	100 (7)
Sparrow	1 (<1)	1 (<1)
Turkeys	3 (2)	14 (1)
Turtles	1 (<1)	1 (<1)
Wild boars	2 (1)	2 (<1)
Yak	1 (<1)	2 (<1)
Not specified	77 (42)	215 (15)

a. Percent adds to more than 100 because most studies and measures included multiple types of animals

References

ABDO, S. M. et al. Detection and molecular identification of Blastocystis isolates from humans and cattle in northern Egypt. Journal of parasitic diseases: official organ of the Indian Society for Parasitology, v. 45, n. 3, p. 738-745, 2021.

ABELLO, J. J. M. et al. Library-independent source tracking of fecal contamination in selected stations and tributaries of Laguna Lake, Philippines. **Journal of water and health,** v. 19, n. 5, p. 846-854, 2021.

ADJEI, A. A., ARMAH, H., RODRIGUES, O., RENNER, L., BORKETEY, P., AYEH-KUMI, P., ADIKU, T., SIFAH, E., AND LARTEY, M. Cryptosporidium spp., a frequent cause of diarrhea among children at the Korle-Bu Teaching Hospital, Accra, Ghana. **Japanese Journal of Infectious Diseases,** v. 57, n. 5, p. 216-219, 2004.

AJJAMPUR, S. S. R. et al. Epidemiology of soil transmitted helminths and risk analysis of hookworm infections in the community: Results from the DeWorm3 Trial in southern India. **PLoS neglected tropical diseases,** v. 15, n. 4, p. e0009338-e0009338, 2021.

ALYOUSEFI, N. A. et al. Factors associated with high prevalence of intestinal protozoan infections among patients in Sana'a City, Yemen. **PLoS One,** v. 6, n. 7, p. e22044, 2011. ISSN 1932-6203 (Electronic)

AMAR, O. A. O. et al. Toxoplasmosis Prevalence in Pregnant Women of Plain Gangetic Region, Allahabad. **JOURNAL OF PURE AND APPLIED MICROBIOLOGY,** v. 9, n. 2, p. 1611-1619, 2015.

ANUAR, T. S. et al. Prevalence and Risk Factors Associated with Entamoeba histolytica/dispar/moshkovskii Infection among Three Orang Asli Ethnic Groups in Malaysia. **Plos One,** v. 7, n. 10, Oct 2012. ISSN 1932-6203.

ANUAR, T. S. et al. Molecular epidemiology of giardiasis among Orang Asli in Malaysia: application of the triosephosphate isomerase gene. **Bmc Infectious Diseases,** v. 14, Feb 2014. ISSN 1471-2334.

AWOBODE, H. O. et al. Shedding proportion of Toxoplasma gondii-like oocysts in feral cats and soil contamination in Oyo State, Nigeria. **Parasite epidemiology and control,** v. 11, p. e00181, 2020. ISSN 2405-6731.

AYINMODE, A. B.; OBEBE, O. O.; OLAYEMI, E. Prevalence of potentially zoonotic gastrointestinal parasites in canine faeces in Ibadan, Nigeria. **Ghana medical journal,** v. 50, n. 4, p. 201-206, 2016. ISSN 0016-9560.

BAKER, K. K. et al. Fecal fingerprints of enteric pathogen contamination in public environments of Kisumu, Kenya, associated with human sanitation conditions and domestic animals. **Environmental science & technology,** v. 52, n. 18, p. 10263-10274, 2018. ISSN 0013-936X.

BANDARANAYAKA, K.; RAJAPAKSE, R.; RAJAKARUNA, R. Potentially zoonotic gastrointestinal parasites of dogs in Lunugala Tea estate community in Central Sri Lanka. **Ceylon Journal of Science,** v. 48, n. 1, p. 43-50, 2019. ISSN 2513-230X.

BARNES, A. N.; ANDERSON, J.D.; MUMMA, J.; MAHMUD, Z.H.; CUMMING, O. The association between domestic animal presence and ownership and household drinking water contamination among peri-urban communities of Kisumu, Kenya. **PLoS one** v. 13, n. 6, p. e0197587, 2018.

BARNES, A. N. et al. Knowledge and practices surrounding zoonotic disease among Mongolian herding households. **Pastoralism,** v. 10, n. 1, p. 1-14, 2020. ISSN 2041-7136.

BARNES, A. N. et al. Zoonotic enteric parasites in Mongolian people, animals, and the environment: Using One Health to address shared pathogens. **PLoS neglected tropical diseases,** v. 15, n. 7, p. e0009543, 2021. ISSN 1935-2735.

BEIROMVAND, M.; PANABAD, E.; RAFIEI, A. Status of intestinal parasitic infections among rural and urban populations, southwestern Iran. **Asian Pacific Journal of Tropical Medicine,** v. 12, n. 3, p. 130, 2019. ISSN 1995-7645.

BERN, C. et al. The Epidemiology of Intestinal Microsporidiosis in Patients with HIV/AIDS in Lima, Peru. **The Journal of Infectious Diseases,** v. 191, n. 10, p. 1658-1664, 2005. ISSN 0022-1899.

BERNAL, R. I. R.; MUÑOZ, O. Factores epidemiológicos relacionados con la seropositividad anti Toxocara canis en niños de pamplona NS, 2015. **CES Salud Pública,** v. 8, n. 2, p. 3-12, 2017. ISSN 2145-9932.

BLACK, R. E. et al. Incidence and etiology of infantile diarrhea and major routes of transmission in Huascar, Peru. **American journal of epidemiology,** v. 129, n. 4, p. 785-799, April 1989

BOEHM, A. B. et al. Occurrence of Host-Associated Fecal Markers on Child Hands, Household Soil, and Drinking Water in Rural Bangladeshi Households. **Environmental Science & Technology Letters**, 2016. ISSN 2328-8930

BOYKO, R. H. et al. Dogs and pigs are transport hosts of Necator americanus: Molecular evidence for a zoonotic mechanism of human hookworm transmission in Ghana. **Zoonoses and public health,** v. 67, n. 5, p. 474-483, 2020. ISSN 1863-1959.

BUBLITZ, D. C. et al. Epidemiology of Pathogenic Enterobacteria in Humans, Livestock, and Peridomestic Rodents in Rural Madagascar. **PLoS One,** v. 9, n. 7, Jul 2014

BUDGE, S. et al. Risk factors and transmission pathways associated with infant Campylobacter spp. prevalence and malnutrition: a formative study in rural Ethiopia. **PloS one,** v. 15, n. 5, p. e0232541, 2020. ISSN 1932-6203.

BUDGE, S. et al. A randomised controlled feasibility trial of a BabyWASH household playspace: the CAMPI study. **PLoS neglected tropical diseases,** v. 15, n. 7, p. e0009514, 2021. ISSN 1935-2735.

BUDGE, S. et al. Do domestic animals contribute to bacterial contamination of infant transmission pathways? Formative evidence from Ethiopia. **Journal of Water and Health,** v. 17, n. 5, p. 655-669, 2019. ISSN 1477-8920.

BUDIONO, N. G. et al. The contribution of domestic animals to the transmission of schistosomiasis japonica in the Lindu Subdistrict of the Central Sulawesi Province, Indonesia. **Veterinary World,** v. 12, n. 10, p. 1591, 2019.

BUKENYA, G. B.; NWOKOLO, N. Compound hygiene, presence of standpipe and the risk of childhood diarrhoea in an urban settlement of Papua New Guinea. **International Journal of Epidemiology,** v. 20, n. 2, p. 534-539, 1991

CABRAL MONICA, T. et al. Socioeconomic factors associated with infection by Toxoplasma gondii and Toxocara canis in children. **Transboundary and emerging diseases,** v. 69, n. 3, p. 1589-1595, 2022.

CAPONE, D. et al. A localized sanitation status index as a proxy for fecal contamination in urban Maputo, Mozambique. **PloS one,** v. 14, n. 10, p. e0224333, 2019. ISSN 1932-6203.

CARON, Y. et al. Stunting, beyond acute diarrhoea: Giardia duodenalis, in Cambodia. **Nutrients,** v. 10, n. 10, p. 1420, 2018. ISSN 2072-6643.

CHARD, A. N. et al. Environmental and spatial determinants of enteric pathogen infection in rural Lao People's Democratic Republic: A cross-sectional study. **PLoS neglected tropical diseases,** v. 14, n. 4, p. e0008180, 2020. ISSN 1935-2735.

CHAVEZ-LINDELL, T. L. et al. An exploratory assessment of human and animal health concerns of smallholder farmers in rural communities of Chimborazo, Ecuador. **PeerJ,** v. 9, p. e12208-e12208, 2022.

CHIODO, P. et al. Related factors to human toxocariasis in a rural community of Argentina. **Memorias do Instituto Oswaldo Cruz,** v. 101, n. 4, p. 397-400, 2006. ISSN 0074-0276

CHUMA, I. S. et al. Epidemiology and RAPD-PCR typing of thermophilic campylobacters from children under five years and chickens in Morogoro Municipality, Tanzania. **BMC infectious diseases,** v. 16, n. 1, p. 1-11, 2016. ISSN 1471-2334.

COCIANCIC, P. et al. Intestinal parasites in canine feces contaminating urban and recreational areas in Ushuaia (Argentina). **Veterinary Parasitology: Regional Studies and Reports,** v. 21, p. 100424, 2020. ISSN 2405-9390.

COELLO-PERALTA, R. D. et al. Presence of Hymenolepis nana and diminuta in rodents of the Las Pinas citadel, in Milagro, Ecuador, and its risk for public health. **Revista mexicana de ciencias pecuarias,** v. 11, n. 4, p. 961-970, 2020. ISSN 2007-1124.

COLLINET-ADLER, S. et al. Environmental indicators of diarrhea in Vellore, India. **American Journal of Tropical Medicine and Hygiene,** v. 85, n. 6, p. 175, 2011. ISSN 0002-9637.

CONAN, A. et al. Animal-related factors associated with moderate-to-severe diarrhea in children younger than five years in western Kenya: a matched case-control study. **PLoS neglected tropical diseases,** v. 11, n. 8, p. e0005795, 2017. ISSN 1935-2735.

CONTRERAS, J. D. et al. Longitudinal Effects of a Sanitation Intervention on Environmental Fecal Contamination in a Cluster-Randomized Controlled Trial in Rural Bangladesh. **Environmental science & technology,** v. 55, n. 12, p. 8169-8179, 2021. ISSN 0013-936X.

CUMBERLAND, P.; HAILU, G.; TODD, J. Active trachoma in children aged three to nine years in rural communities in Ethiopia: prevalence, indicators and risk factors. **Trans R Soc Trop Med Hyg,** v. 99, n. 2, p. 120-7, Feb 2005. ISSN 0035-9203

CVETKOVA, T.; STOYANOVA, K.; PAUNOV, T. Contamination with Toxocara spp. eggs of environmental samples of public places of Varna City, Bulgaria. **Journal of IMAB–Annual Proceeding Scientific Papers,** v. 24, n. 3, p. 2177-2180, 2018. ISSN 1312-773X.

DA SILVA, D. T. G. et al. A longitudinal study of the association between domestic contact with livestock and contamination of household point-of-use stored drinking water in rural Siaya County (Kenya). **International journal of hygiene and environmental health,** v. 230, p. 113602, 2020. ISSN 1438-4639.

DA SILVA, N. M. M. et al. Soil contamination by zoonotic gastrointestinal parasites of mammals in Garanhuns, Pernambuco, Brazil. **Medicina Veterinária (UFRPE),** v. 13, n. 1, p. 65-69, 2019. ISSN 2675-6617.

DANG-XUAN, S. et al. Household exposure to livestock and health in the CHILILAB HDSS cohort, Vietnam. **Asia Pacific Journal of Public Health,** v. 29, n. 5_suppl, p. 72S-83S, 2017. ISSN 1010-5395.

DANIELS, M. E. et al. Cryptosporidium and giardia in humans, domestic animals, and village water sources in rural India. **American Journal of Tropical Medicine and Hygiene,** v. 93, n. 3, p. 596-600, 2015. ISSN 0002-9637.

DANIELS, M. E. et al. Modeling Cryptosporidium and Giardia in Ground and Surface Water Sources in Rural India: Associations with Latrines, Livestock, Damaged Wells, and Rainfall Patterns. **Environ Sci Technol,** v. 50, n. 14, p. 7498-507, Jul 19 2016. ISSN 1520-5851

DAS, R. et al. Nontyphoidal Salmonella among Children under 5 Years Old in Sub-Saharan Africa and South Asia in the Global Enteric Multicenter Study. **The American journal of tropical medicine and hygiene,** v. 106, n. 2, p. 504-512, 2021.

DE BRUYN, J. et al. Does village chicken-keeping contribute to young children's diets and growth? A longitudinal observational study in rural Tanzania. **Nutrients,** v. 10, n. 11, p. 1799, 2018.

DE MACEDO, L. O. et al. Parasites with zoonotic potential in canine fecal samples from Garanhuns, Pernambuco, Brazil. **Medicina Veterinária (UFRPE),** v. 13, n. 2, p. 227-231, 2019. ISSN 2675-6617.

DELAI, R. R. et al. One Health approach on human seroprevalence of anti-Toxocara antibodies, Toxocara spp. eggs in dogs and sand samples between seashore mainland and island areas of southern Brazil. **One health (Amsterdam, Netherlands),** v. 13, p. 100353-100353, 2021.

DORJSUREN, T. et al. Prevalence and risk factors associated with human cystic echinococcosis in rural areas, Mongolia. **PloS one,** v. 15, n. 7, p. e0235399, 2020. ISSN 1932-6203.

DWIVEDI, K. K. et al. Enteric Opportunistic Parasites among HIV Infected Individuals: Associated Risk Factors and Immune Status. **Japanese Journal of Infectious Diseases,** v. 60, p. 76-81, 2007.

EISEN, A. K. A. et al. Soil contamination of a public park by human and canine mastadenovirus, as well as hookworms and Toxocara spp eggs. **Revista do Instituto de Medicina Tropical de São Paulo,** v. 61, 2019. ISSN 1678-9946.

EL-TRAS, W. F. et al. Campylobacter infections in children exposed to infected backyard poultry in Egypt. **Epidemiol Infect,** v. 143, n. 2, p. 308-15, Jan 2015. ISSN 1469-4409 (Electronic)

ERCUMEN, A. et al. Animal feces contribute to domestic fecal contamination: evidence from E. coli measured in water, hands, food, flies, and soil in Bangladesh. **Environmental science & technology,** v. 51, n. 15, p. 8725-8734, 2017. ISSN 0013-936X.

ERCUMEN, A. et al. Do sanitation improvements reduce fecal contamination of water, hands, food, soil, and flies? Evidence from a cluster-randomized controlled trial in rural Bangladesh. **Environmental science & technology,** v. 52, n. 21, p. 12089-12097, 2018. ISSN 0013-936X.

ERCUMEN, A. et al. Poultry ownership associated with increased risk of child diarrhea: cross-sectional evidence from Uganda. **The American Journal of Tropical Medicine and Hygiene,** v. 102, n. 3, p. 526, 2020.

ERISMANN, S. et al. Prevalence of intestinal parasitic infections and associated risk factors among schoolchildren in the Plateau Central and Centre-Ouest regions of Burkina Faso. **Parasites & vectors,** v. 9, n. 1, p. 1-14, 2016. ISSN 1756-3305.

FANG, E. E. et al. Investigating the risk factors for seroprevalence and the correlation between CD4+ T-cell count and humoral antibody responses to Toxoplasma gondii infection amongst HIV patients in the Bamenda Health District, Cameroon. **PloS one,** v. 16, n. 12, p. e0256947-e0256947, 2021.

FERNANDO, S. et al. Epidemiological aspects and risk factors of toxocariasis in a pediatric population in Sri Lanka. **Southeast Asian J Trop Med Public Health,** v. 38, n. 6, p. 983-990, 2007.

FUHRMEISTER, E. R. et al. Effect of sanitation improvements on pathogens and microbial source tracking markers in the rural Bangladeshi household environment. **Environmental science & technology,** v. 54, n. 7, p. 4316-4326, 2020. ISSN 0013-936X.

GAWAD, S. S. A. et al. Detection of Cryptosporidium spp. in diarrheic immunocompetent patients in Beni-Suef, Egypt: insight into epidemiology and diagnosis. **The Korean journal of parasitology,** v. 56, n. 2, p. 113, 2018.

GBOKO, K. D. et al. Risk factors for the carriage of Streptococcus infantarius subspecies infantarius isolated from African fermented dairy products. **PLoS One,** v. 14, n. 11, p. e0225452, 2019. ISSN 1932-6203.

GEBREWAHD, A. et al. Bacteriological quality and associated risk factors of drinking water in Eastern zone, Tigrai, Ethiopia, 2019. **Tropical diseases, travel medicine and vaccines,** v. 6, n. 1, p. 1-7, 2020. ISSN 2055-0936.

GEDA, N. et al. Prevalence of Cryptococcal Antigenemia and associated factors among HIV/AIDS patients on second-line antiretroviral therapy at two hospitals in Western Oromia, Ethiopia. **PloS one,** v. 14, n. 12, p. e0225691, 2019. ISSN 1932-6203.

GELLI, A. et al. Poultry husbandry, water, sanitation, and hygiene practices, and child anthropometry in rural Burkina Faso. **Maternal & child nutrition,** v. 15, n. 4, p. e12818, 2019. ISSN 1740-8695.

GEORGE, C. M. et al. Child mouthing of feces and fomites and animal contact are associated with diarrhea and impaired growth among young children in the Democratic Republic of the Congo: a prospective cohort study (REDUCE Program). **The journal of Pediatrics,** v. 228, p. 110-116. e1, 2021. ISSN 0022-3476.

GEORGE, C. M. et al. Fecal Markers of Environmental Enteropathy are Associated with Animal Exposure and Caregiver Hygiene in Bangladesh. **Am J Trop Med Hyg,** v. 93, n. 2, p. 269-75, Aug 2015. ISSN 0002-9637.

GETANEH, D. K. et al. Prevalence of Escherichia coli O157: H7 and associated factors in under-five children in Eastern Ethiopia. **Plos one,** v. 16, n. 1, p. e0246024, 2021. ISSN 1932-6203.

GHARIEB, R. M. et al. Molecular screening and genotyping of Cryptosporidium species in household dogs and in-contact children in Egypt: risk factor analysis and zoonotic importance. **Vector-Borne and Zoonotic Diseases,** v. 18, n. 8, p. 424-432, 2018. ISSN 1530-3667.

GIZAW, Z. et al. Fecal indicator bacteria along multiple environmental exposure pathways (water, food, and soil) and intestinal parasites among children in the rural northwest Ethiopia. **BMC gastroenterology,** v. 22, n. 1, p. 84-84, 2022.

GLAGN ABDILWOHAB, M.; HAILEMARIAM ABEBO, Z. High prevalence of clinically active trachoma and its associated risk factors among preschool-aged children in arba Minch health and demographic surveillance site, southern Ethiopia. **Clinical Ophthalmology**, p. 3709-3718, 2020. ISSN 1177-5483.

GÓES, G. C. et al. Frequency of enteroparasitoses in preschool children attending daycare centers: a survey applying parasitological and immunological methods. **Revista de Patologia Tropical/Journal of Tropical Pathology,** v. 48, n. 2, p. 121-133, 2019. ISSN 1980-8178.

GRADOS, O. et al. Paediatric campylobacter diarrhoea from household exposure to live chickens in Lima, Peru. **Bulletin of the World Health Organization,** v. 66, n. 3, p. 369-374, 1988.

GURLER, A. T. et al. Role of cat and dog faeces in the contamination of sand playgrounds in public parks by Toxocara spp. **Medycyna Weterynaryjna,** v. 76, n. 08, 2020. ISSN 0025-8628.

HARRIS, A. R. et al. Ruminants Contribute Fecal Contamination to the Urban Household Environment in Dhaka, Bangladesh. **Environmental Science & Technology,** v. 50, n. 9, p. 4642, 2016.

HARVEY, S. A. et al. Domestic poultry-raising practices in a Peruvian shantytown: implications for control of Campylobacter jejuni-associated diarrhea. **Acta Tropica,** v. 86, n. 1, p. 41-54, 4// 2003. ISSN 0001-706X.

HEADEY, D.; HIRVONEN, K. Is Exposure to Poultry Harmful to Child Nutrition? An Observational Analysis for Rural Ethiopia. **PLoS One,** v. 11, n. 8, Aug 2016.

HEADEY, D. et al. Is Exposure to Animal Feces Harmful to Child Nutrition and Health Outcomes? A Multicountry Observational Analysis. **The American journal of tropical medicine and hygiene,** v. 96, n. 4, p. 961-969, 2017. ISSN 1476-1645

HOLCOMB, D. A. et al. Impacts of an Urban Sanitation Intervention on Fecal Indicators and the Prevalence of Human Fecal Contamination in Mozambique. **Environmental science & technology,** v. 55, n. 17, p. 11667-11679, 2021.

HOLCOMB, D. A. et al. Human fecal contamination of water, soil, and surfaces in households sharing poor-quality sanitation facilities in Maputo, Mozambique. **International journal of hygiene and environmental health,** v. 226, p. 113496, 2020. ISSN 1438-4639.

HUDA, T. M. N. et al. Effect of Neighborhood Sanitation Coverage on Fecal Contamination of the Household Environment in Rural Bangladesh. **American Journal of Tropical Medicine and Hygiene,** v. 100, n. 3, p. 717-726, 2019. ISSN 0002-9637.

IWASHITA, H. et al. Molecular epidemiology of Giardia spp. in northern Vietnam: Potential transmission between animals and humans. **Parasite epidemiology and control,** v. 12, p. e00193, 2021. ISSN 2405-6731.

IWASHITA, H. et al. Molecular epidemiology of Cryptosporidium spp. in an agricultural area of northern Vietnam: A community survey. **Parasitology International,** v. 83, p. 102341, 2021. ISSN 1383-5769.

JESKE, S. et al. Intestinal parasites in cancer patients in the South of Brazil. **Brazilian Journal of Biology,** v. 78, p. 574-578, 2017. ISSN 1519-6984.

KAMAU, J. et al. The intersection of land use and human behavior as risk factors for zoonotic pathogen exposure in Laikipia County, Kenya. **PLoS neglected tropical diseases,** v. 15, n. 2, p. e0009143, 2021. ISSN 1935-2735.

KASHINAHANJI, M. et al. Giardia lamblia assemblages A and B isolated from symptomatic and asymptomatic persons in Hamadan, west of Iran. **Journal of Parasitic Diseases,** v. 43, n. 4, p. 616-623, 2019. ISSN 0975-0703.

KAUR, M.; GRAHAM, J. P.; EISENBERG, J. N. S. Livestock Ownership Among Rural Households and Child Morbidity and Mortality: An Analysis of Demographic Health Survey Data from 30 Sub-Saharan African Countries (2005-2015). **Am J Trop Med Hyg,** v. 96, n. 3, p. 741-748, Mar 2017. ISSN 0002-9637.

KHAN, W. et al. Gastrointestinal helminths in dog feces surrounding suburban areas of Lower Dir district, Pakistan: A public health threat. **Brazilian Journal of Biology,** v. 80, p. 511-517, 2019. ISSN 1519-6984.

KLADKEMPETCH, D.; TANGTRONGSUP, S.; TIWANANTHAGORN, S. Ancylostoma ceylanicum: the neglected zoonotic parasite of community dogs in Thailand and its genetic diversity among Asian Countries. **Animals,** v. 10, n. 11, p. 2154, 2020. ISSN 2076-2615.

LABRIQUE, A. B. et al. An Exploratory Case Control Study of Risk Factors for Hepatitis E in Rural Bangladesh. e61351. **PLoS ONE,** v. 8, n. 5, May 2013

LAMBRECHT, N. J. et al. Ruminant-Related Risk Factors are Associated with Shiga Toxin-Producing Escherichia coli Infection in Children in Southern Ghana. **The American journal of tropical medicine and hygiene,** v. 106, n. 2, p. 513-522, 2021.

LAORAKSAWONG, P. et al. Prevalence of Soil-Transmitted Helminth Infections and Associated Risk Factors among Schoolchildren in Nakhon Si Thammarat, Thailand. **Iran J Parasitol,** v. 15, n. 3, p. 440-445, Jul-Sep 2020.

LEUNG, D. et al. Non-typhoidal Salmonella gastroenteritis at a diarrheal hospital in Dhaka, Bangladesh, 1996-2011. **American journal of tropical medicine and hygiene**. 88**:** 661-9 p. 2013.

LI, N. et al. Host-adapted Cryptosporidium and Enterocytozoon bieneusi genotypes in straw-colored fruit bats in Nigeria. **International Journal for Parasitology: Parasites and Wildlife,** v. 8, p. 19-24, 2019. ISSN 2213-2244.

LI, X.-X. et al. Prevalence and risk factors of intestinal protozoan and helminth infections among pulmonary tuberculosis patients without HIV infection in a rural county in P. R. China. **Acta Tropica,** v. 149, p. 19-26, 2015/09/01/ 2015. ISSN 0001-706X.

LOWENSTEIN, C. et al. Determinants of childhood zoonotic enteric infections in a semirural community of Quito, Ecuador. **The American journal of tropical medicine and hygiene,** v. 102, n. 6, p. 1269, 2020.

LUPINDU, A. M. et al. Occurrence and characterization of Shiga toxin-producing Escherichia coli O157:H7 and other non-sorbitol-fermenting E. coli in cattle and humans in urban areas of Morogoro, Tanzania. **Vector-Borne and Zoonotic Diseases,** v. 14, n. 7, p. 503-510, 2014. ISSN 1557-7759

MACCHIONI, F. et al. Intestinal parasitic infections and associated epidemiological drivers in two rural communities of the Bolivian Chaco. **The Journal of Infection in Developing Countries,** v. 10, n. 9, p. 1012-109, 2016.

MACIEL, M. G. et al. Cross-sectional serological survey of human fascioliasis in Canutama Municipality in Western Amazon, Brazil. **Journal of parasitology research,** v. 2018, 2018. ISSN 2090-0023.

MAKALA, R. et al. Seroprevalence of Brucella infection and associated factors among pregnant women receiving antenatal care around human, wildlife and livestock interface in Ngorongoro ecosystem, Northern Tanzania. A cross-sectional study. **BMC infectious diseases,** v. 20, n. 1, p. 1-7, 2020. ISSN 1471-2334.

MALLA, B. et al. Validation of host-specific Bacteroidales quantitative PCR assays and their application to microbial source tracking of drinking water sources in the Kathmandu Valley, Nepal. **Journal of Applied Microbiology,** v. 125, n. 2, p. 609-619, 2018. ISSN 1364-5072.

MALLA, B. et al. Identification of human and animal fecal contamination in drinking water sources in the Kathmandu Valley, Nepal, using host-associated Bacteroidales quantitative PCR assays. **Water,** v. 10, n. 12, p. 1796, 2018. ISSN 2073-4441.

MARQUIS, G. S. et al. Fecal Contamination of Shanty Town Toddlers in Households with Non-Corralled Poultry, Lima Peru. **American Journal of Public Health,** v. 80, n. 2, p. 146-9, Feb 1990.

MAZHAB-JAFARI, K. et al. Prevalence of Toxocara eggs in the soil of public parks of Khorramshahr city, southwest Iran. **Annals of parasitology,** v. 65, n. 4, 2019. ISSN 0043-5163.

MBAE, C. et al. Factors associated with occurrence of salmonellosis among children living in Mukuru slum, an urban informal settlement in Kenya. **BMC Infectious Diseases,** v. 20, n. 1, p. 1-12, 2020. ISSN 1471-2334.

MEDGYESI, D. N. et al. Where Children Play: Young child exposure to environmental hazards during play in public areas in a transitioning internally displaced persons community in Haiti. **International Journal of Environmental Research and Public Health,** v. 15, n. 8, p. 1646, 2018. ISSN 1660-4601.

MEDINA-PINTO, R. A.; RODRÍGUEZ-VIVAS, R. I.; BOLIO-GONZÁLEZ, M. E. Zoonotic intestinal nematodes in dogs from public parks in Yucatán, México. **Biomedica,** v. 38, n. 1, p. 105-110, 2018. ISSN 2590-7379.

MELLO, C. C. S. D. et al. Helminth eggs with zoonotic potential in the vicinity of public schools in southern Brazil. **Revista Brasileira de Parasitologia Veterinária,** v. 29, 2020. ISSN 0103-846X.

MOHAMMAD, S. M. et al. Genotyping of Cryptosporidium species in children suffering from diarrhea in Sharkyia Governorate, Egypt. **Journal of infection in developing countries,** v. 15, n. 10, p. 1539-1546, 2021.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., The PRISMA Group. Preferred Reporting Items for Systematic Reviews and MetaAnalyses: The PRISMA Statement. *PLoS Medicine*. **2009**, 6, e1000097.

MØLBAK, K. et al. Risk factors for diarrheal disease incidence in early childhood: a community cohort study from Guinea-Bissau. **American Journal of Epidemiology,** v. 146, n. 3, p. 273-282, 1997. ISSN 1476-6256.

MONIRA, S. et al. Child mouthing of soil and presence of animals in child sleeping spaces are associated with growth faltering among young children in Dhaka, Bangladesh (CHoBI7 Program). **Tropical Medicine & International Health,** v. 25, n. 8, p. 1016-1023, 2020. ISSN 1360-2276.

MOORE, C. E. et al. Molecular Characterization of Cryptosporidium Species and Giardia duodenalis from Symptomatic Cambodian Children. **PLoS Neglected Tropical Diseases,** v. 10, n. 7, 2016. ISSN 1935-2735

MOSITES, E. et al. Relations between Household Livestock Ownership, Livestock Disease, and Young Child Growth. **J Nutr,** v. 146, n. 5, p. 7, 2016.

MPYET, C. et al. Prevalence of and Risk Factors for Trachoma in Kano State, Nigeria. **PLoS One,** v. 7, n. 7, Jul 2012

MUADICA, A. et al. Risk associations for intestinal parasites in symptomatic and asymptomatic schoolchildren in central Mozambique. **Clinical Microbiology and Infection,** v. 27, n. 4, p. 624-629, 2021. ISSN 1198-743X.

NASR, NA. et al. A holistic approach is needed to control the perpetual burden of soil-transmitted helminth infections among indigenous schoolchildren in Malaysia. **Pathogens and Global Health,** v. 114, n. 3, p 145-159, 2020.

NAVAB-DANESHMAND, T. et al. Escherichia coli contamination across multiple environmental compartments (soil, hands, drinking water, and handwashing water) in urban Harare: Correlations and risk factors. **The American journal of tropical medicine and hygiene**, v. 93, n.3, p. 803, 2018.

NGUI, R. et al. Copro-molecular study of Entamoeba infection among the indigenous community in Malaysia: A first report on the species-specific prevalence of Entamoeba in dogs. **Acta tropica,** v. 204, p. 105334, 2020.

NGURE, F. et al. Exposure to livestock feces and water quality, sanitation, and hygiene (wash) conditions among caregivers and young children: Formative research in rural Burkina Faso. **The American journal of tropical medicine and hygiene,** v. 100, n. 4, p. 998, 2019.

NGURE, F. M. et al. Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. **The American journal of tropical medicine and hygiene,** v. 89, n. 4, p. 709-716, 2013. ISSN 1476-1645

NIGUSIE, A.; BERHE, R.; GEDEFAW, M. Prevalence and associated factors of active trachoma among childeren aged 1-9 years in rural communities of Gonji Kolella district, West Gojjam zone, North West Ethiopia. **BMC Res Notes,** v. 8, p. 641, 2015. ISSN 1756-0500.

OBERHELMAN, R. A. et al. An Intervention-Control Study of Corraling of Free-Ranging Chickens to Control *Campylobacter* Infections Among Children in a Peruvian Periurban Shantytown. ***Am J Trop Med Hyg,*** v. 74, n. 6, p. 6, 2006.

ODAGIRI, M. et al. Human fecal and pathogen exposure pathways in rural Indian villages and the effect of increased latrine coverage. **Water Research,** v. 100, p. 232-244, September 2016

OKOH, A. E.; PER, M.; DU-SAI, D. Prevalence of Toxocara canis eggs in soil samples collected from parks and play grounds in Makurdi, Benue State, Nigeria. **Vom Journal of Veterinary Science,** v. 12, p. 130-133, 2017. ISSN 0331-8753.

ORDIZ, M. I. et al. Environmental Enteric Dysfunction is Associated with Poor Linear Growth and Can be Identified by Host Fecal mRNAs. **Journal of Pediatric Gastroenterology and Nutrition**, 2016. ISSN 1536-4801

OSBJER, K. et al. Household practices related to disease transmission between animals and humans in rural Cambodia. **BMC Public Health,** v. 15, p. 476, May 09 2015. ISSN 1471-2458 (Electronic)

PARVEZ, S. M. et al. Microbiological contamination of young children's hands in rural Bangladesh: Associations with child age and observed hand cleanliness as proxy. **PLoS One,** v. 14, n. 9, p. e0222355, 2019. ISSN 1932-6203.

PARVEZ, S. M. et al. Escherichia coli contamination of child complementary foods and association with domestic hygiene in rural Bangladesh. **Tropical Medicine & International Health,** v. 22, n. 5, p. 547-557, 2017. ISSN 1360-2276.

PEÑA-QUISTIAL, M. G. et al. Prevalence and associated risk factors of Intestinal parasites in rural high-mountain communities of the Valle del Cauca—Colombia. **PLoS Neglected Tropical Diseases,** v. 14, n. 10, p. e0008734, 2020. ISSN 1935-2735.

PEREIRA, M. D. G. C.; ATWILL, E. R.; BARBOSA, A. P. Prevalence and associated risk factors for Giardia lamblia infection among children hospitalized for diarrhea in Goiânia, Goiás State, Brazil. **Revista do Instituto de Medicina Tropical de São Paulo,** v. 49, p. 139-145, 2007. ISSN 1678-9946.

PRASETYO, R. H. Prevalence of two zoonotic intestinal parasites Strongyloides stercoralis and Hymenolepis nana in house rat from a slum area in Surabaya District, East Java, Indonesia. **Indian Veterinary Journal,** v. 96, n. 12, p. 9-10, 2019. ISSN 0019-6479.

QUADROS, R. M. D. et al. Potential cross-contamination of similar Giardia duodenalis assemblage in children and pet dogs in southern Brazil, as determined by PCR-RFLP. **Revista do Instituto de Medicina Tropical de São Paulo,** v. 58, 2016. ISSN 1678-9946.

RAIČEVIĆ, J. G.; PAVLOVIĆ, I. N.; GALONJA-COGHILL, T. A. Canine intestinal parasites as a potential source of soil contamination in the public areas of Kruševac, Serbia. **The Journal of Infection in Developing Countries,** v. 15, n. 01, p. 147-154, 2021. ISSN 1972-2680.

RANDREMANANA, R. V. et al. Etiologies, Risk Factors and Impact of Severe Diarrhea in the Under-Fives in Moramanga and Antananarivo, Madagascar. **Plos One,** v. 11, n. 7, Jul 2016. ISSN 1932-6203.

REBIH, N. et al. Molecular and epidemiological characterization of Giardia intestinalis assemblages detected in Djelfa, Algeria. **Journal of parasitic diseases,** v. 44, n. 2, p. 281-288, 2020. ISSN 0975-0703.

REICHERT, F. et al. Prevalence and Risk Factors of Hookworm-Related Cutaneous Larva Migrans (HrCLM) in a Resource-Poor Community in Manaus, Brazil. **PLoS Neglected Tropical Diseases,** v. 10, n. 3, 2016 Mar 24

REID, B. et al. Characterizing potential risks of fecal–oral microbial transmission for infants and young children in Rural Zambia. **The American Journal of Tropical Medicine and Hygiene,** v. 98, n. 3, p. 816, 2018.

RIBAS, A. et al. Helminths in rodents from wet markets in Thailand. **Helminthologia,** v. 53, n. 4, p. 326-330, 2016.

RIVERO, M. et al. Epidemiology of hemolytic uremic syndrome in two regions of Buenos Aires Province. **Medicina,** v. 73, n. 2, p. 127-135, 2013. ISSN 0025-7680.

RIVERO, M. R. et al. Environmental and socio-demographic individual, family and neighborhood factors associated with children intestinal parasitoses at Iguazú, in the subtropical northern border of Argentina. **PLoS neglected tropical diseases,** v. 11, n. 11, p. e0006098, 2017. ISSN 1935-2735.

RUANG-AREERATE, T. et al. Zoonotic Transmission of Blastocystis Subtype 1 among People in Eastern Communities of Thailand: Organic Fertilizer from Pig Feces as a Potential Source. **Microbiology spectrum,** v. 9, n. 2, p. e0036221-e0036221, 2021.

SAAED, F. M.; ONGERTH, J. E. Giardia and Cryptosporidium in children with diarrhea, Kufra, Libya, a North African migration route city. **International journal of hygiene and environmental health,** v. 222, n. 5, p. 840-846, 2019. ISSN 1438-4639.

SACK, A. et al. Potential risk factors for zoonotic disease transmission among Mongolian herder households caring for horses and camels. **Pastoralism,** v. 8, n. 1, p. 1-11, 2018. ISSN 2041-7136.

SACK, A. et al. A One Health Approach to Defining Animal and Human Helminth Exposure Risks in a Tribal Village in Southern India. **The American journal of tropical medicine and hygiene,** v. 105, n. 1, p. 196-203, 2021. ISSN 0002-9637.

SAMRA, N. A. et al. Cryptosporidium genotypes in children and calves living at the wildlife or livestock interface of the Kruger National Park, South Africa. **Onderstepoort Journal of Veterinary Research,** v. 83, n. 1, p. 1-7, 2016. ISSN 0030-2465.

SARDARIAN, K. et al. Prevalence of zoonotic intestinal parasites in household and stray dogs in rural areas of Hamadan, Western Iran. **Trop Biomed,** v. 32, n. 2, p. 240-6, 2015.

SAZZAD, H. M. et al. Risk factors associated with blood exposure for sporadic hepatitis E in Dhaka, Bangladesh. **The American journal of tropical medicine and hygiene,** v. 97, n. 5, p. 1437, 2017.

SCHIAFFINO, F. et al. Associations among Household Animal Ownership, Infrastructure, and Hygiene Characteristics with Source Attribution of Household Fecal Contamination in Peri-Urban Communities of Iquitos, Peru. **Am J Trop Med Hyg,** v. 104, n. 1, p. 372-381, Jan 2021. ISSN 0002-9637 (Print)

SCHMIDT, W. P. et al. Exposure to cows is not associated with diarrhoea or impaired child growth in rural Odisha, India: a cohort study. **Epidemiol Infect,** v. 144, n. 1, p. 53-63, Jan 2016. ISSN 1469-4409

SCHRIEWER, A. et al. Human and animal fecal contamination of community water sources, stored drinking water and hands in rural India measured with validated microbial source tracking assays. **American Journal of Tropical Medicine and Hygiene,** v. 93, n. 3, p. 509-516, 2015. ISSN 0002-9637.

SCHURER, J. M. et al. Long-tailed macaques (Macaca fascicularis) in urban landscapes: gastrointestinal parasitism and barriers for healthy coexistence in northeast Thailand. **The American Journal of Tropical Medicine and Hygiene,** v. 100, n. 2, p. 357, 2019.

SHEHAB, A. Y. et al. Intestinal parasites among humans and their livestock animals in a rural community in Gharbia governorate, Egypt. **Journal of Parasitic Diseases,** v. 45, n. 1, p. 96-100, 2021. ISSN 0975-0703.

SHRESTHA, A. et al. Association of nutrition, water, sanitation and hygiene practices with children's nutritional status, intestinal parasitic infections and diarrhoea in rural Nepal: a cross-sectional study. **BMC public health,** v. 20, n. 1, p. 1-21, 2020. ISSN 1471-2458.

SKHAL, D. et al. Prevalence of Giardia duodenalis assemblages and sub-assemblages in symptomatic patients from Damascus city and its suburbs. **Infection, Genetics and Evolution,** v. 47, p. 155-160, 2017. ISSN 1567-1348.

SOBOKSA, N. E. Environmental and Behavioral Factors Associated with Handwashing With Soap After Defecation in a Rural Setting of 2 Districts of the Jimma Zone, Ethiopia. **Environmental health insights,** v. 16, p. 11786302221091421-11786302221091421, 2022.

SPENCER, L. A.; IRWIN, M. T. Cryptosporidium and Giardia prevalence amongst lemurs, humans, domestic animals and black rats in Tsinjoarivo, Madagascar. **Heliyon,** v. 6, n. 11, p. e05604, 2020. ISSN 2405-8440.

SPRENGER, L. K.; GREEN, K. T.; MOLENTO, M. B. Geohelminth contamination of public areas and epidemiological risk factors in Curitiba, Brazil. **Revista brasileira de parasitologia veterinária = Brazilian journal of veterinary parasitology:** Órgão Oficial do Colégio Brasileiro de Parasitologia Veterinária, v. 23, n. 1, p. 69-73, 2014. ISSN 1984-2961.

SUBRATA, I. M. et al. EPIDEMIOLOGICAL AND MOLECULAR ANALYSIS OF TOXOPLASMA GONDII IN FAECAL SAMPLES OF CATS OBTAINED FROM HOUSE OF MATERNAL IN BALI. **Bali Medical Journal,** v. 4, n. 2, p. 68-75, 2015. ISSN 2089-1180.

SUWANNARONG, K.; CHAPMAN, R. S. Characteristics associated with contact with rodents in, around, and outside homes in Khon Kaen Province, Thailand. **Am J Trop Med Hyg,** v. 92, n. 4, p. 784-90, Apr 2015. ISSN 1476-1645 (Electronic)

TANABE, M. B. et al. Geospatial analysis of the associations between environmental contamination with livestock feces and children with chronic fascioliasis in the Anta province of Cusco, Peru. **PLoS neglected tropical diseases,** v. 16, n. 6, p. e0010499-e0010499, 2022.

THIEM, V. D. et al. Animal livestock and the risk of hospitalized diarrhoea in children under 5 years in Vietnam. **Tropical Medicine & International Health,** v. 17, n. 5, p. 613-621, 2012. ISSN 1360-2276.

TORONDEL, B. et al. Laboratory development and field testing of sentinel toys to assess environmental faecal exposure of young children in rural India. **Transactions of The Royal Society of Tropical Medicine and Hygiene,** v. 109, n. 6, p. 386-392, 2015. ISSN 0035-9203.

TUN, S. et al. Detection of Helminth Eggs and Identification of Hookworm Species in Stray Cats, Dogs and Soil from Klang Valley, Malaysia. **PLoS One,** v. 10, n. 12, Dec 2015

UGA, S. et al. Parasite egg contamination of vegetables from a suburban market in Hanoi, Vietnam. **Nepal Medical College journal: NMCJ,** v. 11, n. 2, p. 75-78, 2009.

UTAAKER, K. S. et al. Not just a walk in the park: occurrence of intestinal parasites in dogs roaming recreational parks in Chandigarh, Northern India. **Veterinary Parasitology: Regional Studies and Reports,** v. 14, p. 176-180, 2018. ISSN 2405-9390.

VASCO, K.; GRAHAM, J. P.; TRUEBA, G. Detection of Zoonotic Enteropathogens in Children and Domestic Animals in a Semirural Community in Ecuador. **Appl Environ Microbiol,** v. 82, n. 14, p. 4218-24, Jul 15 2016. ISSN 1098-5336 (Electronic).

VERDEJA, M. et al. Water, sanitation, and hygiene factors associated with child illness in Tanzania. **Health,** v. 11, p. 827-840, 2019. ISSN 1949-5005.

VILA-GUILERA, J. et al. Towards transformative WASH: an integrated case study exploring environmental, sociocultural, economic and institutional risk factors contributing to infant enteric infections in rural tribal India. **BMC Public Health,** v. 21, n. 1, p. 1-15, 2021. ISSN 1471-2458.

VUJCIC, J. et al. Toys and toilets: cross-sectional study using children's toys to evaluate environmental faecal contamination in rural Bangladeshi households with different sanitation facilities and practices. **Tropical Medicine & International Health,** v. 19, n. 5, p. 528-536, 2014.

WALTEROS-CASAS, H.A. et al. Identificación de ecto y endoparásitos en palomas domésticas (Columba livia) del área urbana de Villavicencio, Meta, Colombia. **Revista MVZ Córdoba,** v. 26, n. 3, p. e2157-e2157, 2021. ISSN 1909-0544.

WANYIRI, J. W. et al. Cryptosporidiosis in HIV/AIDS Patients in Kenya: Clinical Features, Epidemiology, Molecular Characterization and Antibody Responses. **The American Journal of Tropical Medicine and Hygiene,** v. 91, n. 2, p. 319-328, 2014.

WEGAYEHU, T.; ADAMU, H.; PETROS, B. Prevalence of Giardia duodenalis and Cryptosporidium species infections among children and cattle in North Shewa Zone, Ethiopia. **BMC infectious diseases,** v. 13, n. 1, p. 1-7, 2013. ISSN 1471-2334.

WOLDE, A. et al. Isolation of Escherichia coli and Its Associated Risk Factor from Diarrheic Children in Wolaita Sodo Town, Southern Ethiopia. **Research and reports in tropical medicine,** v. 12, p. 227-234, 2021.

WOLKING, D. J. et al. Boma to banda - a disease sentinel concept for reduction of diarrhoea. **Pastoralism: Research, Policy and Practice,** v. 6, n. 13, p. (4 July 2016), 2016. ISSN 2041-7136.

WUMBA, R. et al. Epidemiology, clinical, immune, and molecular profiles of microsporidiosis and cryptosporidiosis among HIV/AIDS patients. **International Journal of General Medicine,** v. 5, p. 603-611, 07/19 2012. ISSN 1178-7074.

YAHAYA, R.; DOGARA, M. Prevalence of Cryptosporidium species and Giardia intestinalis among patients in a secondary health facility, Dutse, Jigawa State, Nigeria. **Nigerian Journal of Parasitology,** v. 39, n. 1, p. 84-90, 2018. ISSN 1117-4145.

YOSHIKAWA, H. et al. Molecular survey of Blastocystis sp. from humans and associated animals in an Indonesian community with poor hygiene. **Parasitology international,** v. 65, n. 6, p. 780-784, 2016. ISSN 1383-5769.

ZAIN, S. M.; RAHMAN, R.; LEWIS, J. Stray animal and human defecation as sources of soil-transmitted helminth eggs in playgrounds of Peninsular Malaysia. **Journal of helminthology,** v. 89, n. 6, p. 740-747, 2015. ISSN 0022-149X.

ZAMORA-VÉLEZ, A. et al. Detection and genotypes of Toxoplasma gondii DNA in feces of domestic cats in Colombia. **Parasite,** v. 27, 2020.

ZANAJ, V.; RRAPTI, D.; BAKALLI, M. Public places contamination in Tirana from dogs intestinal geonematodis. **Journal of coastal life medicine,** v. 4, n. 9, p. 714, 2016. ISSN 2309-5288.

ZONTA, M. L. et al. Intestinal parasitosis, undernutrition and socio-environmental factors in schoolchildren from Clorinda Formosa, Argentina. **Revista de Salud Pública,** v. 21, p. 224-231, 2020. ISSN 0124-0064.

ZONTA, M. L. et al. Parasitosis intestinales y factores socioambientales: Estudio preliminar en una población de horticultores. **Salud (i) ciencia (Impresa)**, p. 814-823, 2016.

6.2. Research aim 3 Supporting information

Table S 4. Table of survey items grouped by sub-domain and post-PCA results

Item #	Sub-domain and associated survey items	PCA result	Reason for dropping
	Child Environment (CE)		
CE1	Production chickens spend time outside near the house	Dropped	All responded "never"
CE2	Production chickens enter the house	Dropped	All responded "never"
CE3	Production chickens sleep inside the house	Dropped	All responded "never"
CE4	Ducks spend time outside near the house	Dropped	NZP, not relevant for this sample
CE5	Ducks enter the house	Dropped	NZP, not relevant for this sample
CE6	Ducks sleep inside the house	Dropped	All participants responded "never"
CE7	Turkeys spend time outside near the house	Dropped	All participants responded "never"
CE8	Turkeys enter the house	Dropped	All participants responded "never"
CE9	Turkeys sleep inside the house	Dropped	All participants responded "never"
CE10	Guinea pigs spend time outside near the house	Dropped	All participants responded "never"
CE11	Guinea pigs enter the house	Dropped	All participants responded "never"
CE12	Guinea pigs sleep inside the house	Dropped	All participants responded "never"
CE13	Dogs spend time outside near the house	CE dog principal component (PC)	--
CE14	Dogs enter the house	CE maternal PC	--
CE15	Dogs sleep inside the house	CE dog PC	--
CE16	Pigs outside the house near or in the yard	Dropped	NZP, all loadings <|0.4|

Item #	Sub-domain and associated survey items	PCA result	Reason for dropping
	Child Environment (CE)		
CE17	Pigs enter the house	Dropped	NZP, not relevant for this sample
CE18	Pigs sleep inside the house	Dropped	NZP, not relevant for this sample
CE19	Cattle spend time outside near the house	Dropped	All participants responded “never”
CE20	Cattle enter the house	Dropped	All participants responded “never”
CE21	Cattle sleep inside the house	Dropped	All participants responded “never”
CE22	Dairy cattle spend time outside near the house	CE dairy cattle PC	--
CE23	Dairy cattle enter the house	Dropped	All participants responded “never”
CE24	Dairy cattle sleep in the house	Dropped	All participants responded “never”
CE25	Horses/mules/donkeys spend time outside near the house	Dropped	NZP, not relevant for this sample
CE26	Horses/mules/donkeys enter the house	Dropped	All participants responded “never”
CE27	Horses/mules/donkeys sleep inside the house	Dropped	All participants responded “never”
CE28	Sheep/goats spend time outside near the house	Dropped	NZP, not relevant for this sample
CE29	Sheep/goats enter the house	Dropped	NZP, not relevant for this sample
CE30	Sheep/goats sleep inside the house	Dropped	NZP, not relevant for this sample
CE31	Cats spend time outside near the house	CE cat PC	--
CE32	Cats enter the house	CE cat PC	--
CE33	Cats sleep inside the house	CE cat PC	--
CE34	Creole chickens sleep inside the house	Dropped	NZP, all loadings <|0.4|
CE35	Creole chickens enter the house	CE creole chicken PC	--

Item #	Sub-domain and associated survey items	PCA result	Reason for dropping
	Child Environment (CE)		
CE36	Creole chickens sleep inside the house	CE creole chicken PC	--
CE37	Bushrats spend time outside near the house	Dropped	All participants responded "never"
CE38	Bushrats enter the house	Dropped	All participants responded "never"
CE39	Bushrats sleep inside the house	Dropped	All participants responded "never"
CE40	Rats/rodents spend time outside near the house	Dropped	NZP, not relevant for this sample
CE41	Rats/rodents enter the house	Dropped	NZP, not relevant for this sample
CE42	Rats/rodents sleep inside the house	Dropped	NZP, not relevant for this sample
CE43	Rabbits spend time outside near the house	Dropped	NZP, not relevant for this sample
CE44	Rabbits enter the house	Dropped	NZP, not relevant for this sample
CE45	Rabbits sleep inside the house	Dropped	NZP, not relevant for this sample
CE46	Production chicken poop outside the house near or in the yard	Dropped	All participants responded "never"
CE47	Production chicken poop inside the house	Dropped	All participants responded "never"
CE48	Duck poop outside the house near or in the yard	Dropped	NZP, not relevant for this sample
CE49	Duck poop inside the house	Dropped	NZP, not relevant for this sample
CE50	Turkey poop outside the house near or in the yard	Dropped	All participants responded "never"
CE51	Turkey poop inside the house	Dropped	All participants responded "never"
CE52	Guinea pig poop outside the house near or in the yard	Dropped	All participants responded "never"
CE53	Guinea pig poop inside the house	Dropped	All participants responded "never"

Item #	Sub-domain and associated survey items	PCA result	Reason for dropping
	Child Environment (CE)		
CE54	Dog poop outside the house near or in the yard	CE dog PC	--
CE55	Dog poop inside the house	Dropped	NZP, all loadings <|0.4|
CE56	Pig poop outside the house near or in the yard	Dropped	NZP, not relevant for this sample
CE57	Pig poop inside the house	Dropped	All participants responded "never"
CE58	Cattle poop outside the house near or in the yard	Dropped	All participants responded "never"
CE59	Cattle poop inside the house	Dropped	All participants responded "never"
CE60	Dairy cattle poop outside the house near or in the yard	CE dairy cattle PC	--
CE61	Dairy cattle poop inside the house	Dropped	All participants responded "never"
CE62	Horses/mule/donkey poop outside the house near or in the yard	Dropped	NZP, all loadings <|0.4|
CE63	Horses/mule/donkey poop inside the house	Dropped	All participants responded "never"
CE64	Sheep/goat poop outside the house near or in the yard	Dropped	All participants responded "never"
CE65	Sheep/goat poop inside the house	Dropped	All participants responded "never"
CE66	Cat poop outside the house near or in the yard	CE cat PC	--
CE67	Cat poop inside the house	Dropped	NZP, all loadings <|0.4|
CE68	Creole chicken poop outside the house near or in the yard	CE creole chicken PC	--
CE69	Creole chicken poop inside the house	CE creole chicken PC	--
CE70	Bushrat poop outside the house near or in the yard	Dropped	All participants responded "never"

Item #	Sub-domain and associated survey items	PCA result	Reason for dropping
	Child Environment (CE)		
CE71	Bushrat poop inside the house	Dropped	All participants responded "never"
CE72	Rat/rodent poop outside the house near or in the yard	Dropped	NZP, not relevant for this sample
CE73	Rat/rodent poop inside the house	Dropped	NZP, not relevant for this sample
CE74	Rabbit poop outside the house near or in the yard	Dropped	NZP, not relevant for this sample
CE75	Rabbit poop inside the house	Dropped	NZP, not relevant for this sample
CE76	Poop from an unknown type of animal outside the house near or in the yard	Dropped	All participants responded "never"
CE77	Poop from an unknown type of animal inside the house	Dropped	All participants responded "never"
CE90	House member (apart from mother and child under 5 years) work or care for an animal	CE dairy cattle PC	--
CE91	Mother or someone who lives with you put or throw leftover food outside for an animal	Dropped	All loadings <|0.4|
CE92	Mother personally feeds or gives water to an animal	CE maternal PC	--
CE93	Mother personally touches or plays with an animal	CE maternal PC	--
CE94	Mother personally bathes, cleans, or grooms an animal	CE maternal PC	--
CE95	Mother personally cleans the habitat or place where an animal sleeps and/or defecates	CE maternal PC	--
CE96	Mother personally cares for an animal that was sick	Dropped	NZP, all loadings <|0.4|
CE97	Mother personally eliminates or cleans the poop of an animal	CE maternal PC	--

Item #	Sub-domain and associated survey items	PCA result	Reason for dropping
	Child Behavior (CB)		
CB78	Child plays on the floor of the house without a rug or playmat	Dropped	All loadings <|0.4|
CB79	Child plays inside the house in an area where an animal spends time or sleeps	Dropped	All loadings <|0.4|
CB80	Child plays with or carries around shoes like a toy	CB play and mouthing PC	
CB81	Child plays in soil or dirt outside the house	CB play and mouthing PC	--
CB82	Child play in sand outside the house	Dropped	Consolidated with CB81 due to high correlations (p>0.9)
CB83	Child plays outside the house in an area where an animal lives or sleeps	CB play and mouthing PC	--
CB84	Child plays outside the house without shoes on	CB play and mouthing PC	--
CB85	Child puts objects or toys that had contact with the floor inside the house in their mouth	CB play and mouthing PC	--
CB86	Child puts objects or toys that had contact with the dirt outside the house in their mouth	CB play and mouthing PC	--
CB87	Child puts dirt or soil in their mouth	CB play and mouthing PC	--
CB88	Child put sand in their mouth	Dropped	Consolidated with CB87 due to high correlations (p>0.9)
CB89	Child puts shoes in their mouth	CB play and mouthing PC	--
CB98	Child feeds or gives water or helps others feed or give water to an animal	CB animal caregiving and feces management PC	--

Item #	Sub-domain and associated survey items	PCA result	Reason for dropping
	Child Behavior (CB)		
CB99	Child touches or plays with an animal	CB animal caregiving and feces management PC	--
CB100	Child bathes, cleans, or grooms or helps others bathe, clean, or groom an animal	CB animal caregiving and feces management PC	--
CB101	Child cleans or helps others clean the habitat or place where an animal sleeps and/or defecates	CB animal caregiving and feces management PC	--
CB102	Child cares for or helps others care for an animal that was sick	CB animal caregiving and feces management PC	--
CB103	Child touches or plays with objects used to remove or clean animal poop such as brooms or shovels	Dropped	NZP, all loadings <|0.4|
CB104	Child touches, removes, or cleans animal poop	CB animal caregiving and feces management PC	--
CB105	Child put animal poop in their mouth	Dropped	All participants responded “never”

Table S 5. Child sex-disaggregated demographic characteristics (*n*=297)

Characteristics	**Total**		**Male**		**Female**	
	n	(%)	*n*	(%)	*n*	(%)
Number of participants	297		144	(48.5)	153	(51.5)
Maternal characteristics						
Age (mean [std] in years)	29	(8.0)	30	(9.0)	29	(8.0)
Ethnicity						
Afro-Ecuadorian	221	(74.4)	108	(75.0)	113	(73.9)
Mestizo	70	(23.6)	32	(22.2)	38	(24.8)
Indigenous - Chachi	2	(0.7)	2	(1.4)	0	(0.0)
Manabí	3	(1.1)	1	(0.7)	2	(1.3)
Other	1	(0.4)	1	(0.7)	0	(0.0)
Education (mean [std] in years)	11.5	(3.5)	12	(3.5)	11	(3.5)
Child characteristics						
Age (mean [std] in months)	33	(15.5)	34	(15.0)	32	(16.0)
Currently breastfed	34	(11.4)	12	(8.3)	22	(14.4)
Symptoms in last 7 days						
Diarrhea	40	(13.5)	19	(13.2)	21	(13.7)
Fever	75	(25.3)	43	(29.9)	32	(20.9)
Vomit	23	(7.7)	10	(6.9)	13	(8.5)
Blood in stool	1	(0.3)	1	(0.7)	0	(0.0)
Household characteristics						
Number of people* (mean [std])	5	(2.5)	5.0	(2.0)	5	(2.0)
Owns animal(s)	165	(55.6)	82	(56.9)	83	(54.2)
Dogs	115	(38.7)	60	(41.7)	55	(35.9)
Cats	62	(20.9)	26	(18.1)	36	(23.5)
Creole chickens	35	(11.8)	18	(12.5)	17	(11.1)
Ducks	3	(1.0)	1	(0.7)	2	(1.3)
Dairy cattle	2	(0.7)	2	(1.4)	0	(0.0)
Horses	1	(0.3)	0	(0.0)	1	(0.7)
Pigs	12	(4.0)	6	(4.2)	6	(3.9)
Rabbits	7	(2.4)	3	(2.1)	4	(2.6)
Source of drinking water						
Piped	54	(18.2)	25	(17.4)	29	(19.0)
Bottled/purchased	170	(57.2)	85	(59.0)	85	(55.6)
Protected well	9	(3.0)	3	(2.1)	6	(3.9)
Rain water	43	(14.5)	20	(13.9)	23	(15.0)
Unprotected well	1	(0.3)	1	(0.7)	0	(0.0)
River water	4	(1.3)	2	(1.4)	2	(1.4)
Tanker-truck	16	(5.4)	9	(6.2)	7	(4.6)
Treat drinking water	88	(29.6)	43	(29.9)	45	(29.4)
Source(s) of water for child+						
Piped	108	(36.4)	59	(41.0)	49	(32.0)
Bottled/purchased	81	(27.3)	32	(23.6)	47	(30.7)
Protected well	26	(8.8)	11	(7.6)	15	(9.8)
Rain water	49	(16.5)	21	(14.6)	28	(18.3)
River water	11	(3.7)	5	(3.5)	6	(3.3)
Tanker-truck	32	(10.8)	18	(12.5)	14	(9.2)
Treat water for child	114	(38.4)	52	(36.1)	62	(40.5)

**n*=292, Five observations have missing values

+Participants could report more than one source of water for their child so totals may add to more than 100%

Table S 6. Child exposure item frequencies (n=297)

Sub-domain and associated survey items	Frequency (%)					
	Never	**Rarely**	**Sometimes**	**Frequently**	**Frequency ratio**	**Percent unique data points**
***Child Environment (CE)* – Measure items**						
CE13. Dogs spend time outside near the house	32 (10.8)	5 (1.7)	17 (5.7)	243 (81.8)	7.6	1.3
CE14. Dogs enter the house	167 (56.2)	25 (8.4)	33 (11.1)	72 (24.2)	2.3	1.3
CE15. Dogs sleep inside the house	259 (87.2)	5 (1.7)	3 (1.0)	30 (10.1)	8.6	1.3
CE22. Dairy cattle spend time outside near the house	285 (96.0)	1 (0.3)	4 (1.3)	7 (2.4)	40.7	1.3
CE31. Cats spend time outside near the house	149 (50.2)	7 (2.4)	17 (5.7)	124 (41.8)	1.2	1.3
CE32. Cats enter the house	185 (62.3)	6 (2.0)	34 (11.4)	72 (24.2)	2.6	1.3
CE33. Cats sleep inside the house	249 (83.8)	2 (0.7)	9 (3.0)	37 (12.5)	6.7	1.3
CE34. Creole chickens spend time outside near the house	216 (72.7)	2 (0.7)	5 (1.7)	74 (24.9)	2.9	1.3
CE35. Creole chickens enter the house	267 (89.9)	6 (2.0)	8 (2.7)	16 (5.4)	16.7	1.3
CE54. Dog poop outside the house near or in the yard	117 (39.4)	13 (4.4)	42 (14.1)	125 (42.1)	1.1	1.3
CE58. Dairy cattle poop outside the house near or in the yard	294 (99.0)	1 (0.3)	2 (0.7)	0 (0.0)	147.0	1.0
CE66. Cat poop outside the house near or in the yard	284 (95.6)	1 (0.3)	5 (1.7)	7 (2.4)	40.6	1.3
CE68. Creole chicken poop outside the house near or in the yard	254 (85.5)	4 (1.3)	5 (1.7)	34 (11.4)	7.5	1.3
CE69. Creole chicken poop inside the house	289 (97.3)	2 (0.7)	2 (0.7)	4 (1.3)	72.3	1.3
CE90. House member (apart from mother and child under 5 years) work or care for an animal	263 (88.6)	19 (6.4)	9 (3.0)	6 (2.0)	13.8	1.3
CE92. Mother personally feeds or gives water to an animal	151 (50.8)	4 (1.3)	16 (5.4)	126 (42.4)	1.2	1.3
CE93. Mother personally touches or plays with an animal	196 (66.0)	11 (3.7)	16 (5.4)	74 (24.9)	2.6	1.3
CE94. Mother personally bathes, cleans, or grooms an animal	241 (81.1)	4 (1.3)	17 (5.7)	35 (11.8)	6.9	1.3
CE95. Mother personally cleans the habitat or place where an animal sleeps and/or defecates	210 (70.7)	7 (2.4)	17 (5.7)	63 (21.2)	3.3	1.3
CE97. Mother personally eliminates or cleans the poop of an animal	203 (68.4)	3 (1.0)	24 (8.1)	67 (22.6)	3.0	1.4
***Child Behavior (CB)* – Measure items**						
CB80. Child plays with or carries around shoes like a toy	73 (24.6)	13 (4.4)	39 (13.1)	172 (57.9)	2.4	1.3
CB81. Child plays in soil or dirt outside the house	54 (18.2)	27 (9.1)	35 (11.8)	181 (60.9)	3.4	1.3

Sub-domain and associated survey items	Frequency (%)					
	Never	Rarely	Sometimes	Frequently	Frequency ratio	Percent unique data points
***Child Behavior (CB)* – Measure items**						
CB83. Child plays outside the house in an area where an animal lives or sleeps	100 (33.7)	29 (9.8)	35 (11.8)	133 (44.8)	1.3	1.3
CB84. Child plays outside the house without shoes on	119 (40.1)	15 (5.1)	43 (14.5)	120 (40.4)	1.0	1.3
CB85. Child puts objects or toys that had contact with the floor inside the house in their mouth	120 (40.4)	22 (7.4)	38 (12.8)	117 (39.4)	1.0	1.3
CB86. Child puts objects or toys that had contact with the dirt outside the house in their mouth	215 (72.4)	7 (2.4)	18 (6.1)	57 (19.2)	3.8	1.3
CB87. Child puts dirt or soil in their mouth	243 (81.8)	10 (3.4)	8 (2.7)	36 (12.1)	6.8	1.3
CB89. Child puts shoes in their mouth	217 (73.1)	10 (3.4)	24 (8.1)	46 (15.5)	4.7	1.3
CB98. Child feeds or gives water or helps others feed or give water to an animal	253 (85.2)	9 (3.0)	11 (3.7)	24 (8.1)	10.5	1.3
CB99. Child touches or plays with an animal	159 (53.5)	20 (6.7)	25 (8.4)	93 (31.3)	1.7	1.3
CB100. Child bathes, cleans, or grooms or helps others bathe, clean, or groom an animal	282 (94.9)	2 (0.7)	4 (1.3)	9 (3.0)	31.3	1.3
CB101. Child cleans or helps others clean the habitat or place where an animal sleeps and/or defecates	289 (97.3)	1 (0.3)	3 (1.0)	4 (1.3)	72.3	1.3
CB102. Child cares for or helps others care for an animal that was sick	294 (99.0)	1 (0.3)	2 (0.7)	0 (0.0)	147.0	1.0
CB104. Child touches, removes, or cleans animal poop	293 (98.7)	1 (0.3)	2 (0.7)	1 (0.3)	146.5	1.3
***Child Environment (CE)* – Deleted items**						
CE1. Production chickens spend time outside near the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE2. Production chickens enter the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE3. Production chickens sleep inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE4. Ducks spend time outside near the house	292 (98.3)	1 (0.3)	1 (0.3)	3 (1.0)	97.3	1.3
CE5. Ducks enter the house	295 (99.3)	1 (0.3)	1 (0.3)	0 (0.0)	295.0	1.0
CE6. Ducks sleep inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE7. Turkeys spend time outside near the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE8. Turkeys enter the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3

Sub-domain and associated survey items	Frequency (%)					
	Never	Rarely	Sometimes	Frequently	Frequency ratio	Percent unique data points
***Child Environment (CE)* – Deleted items**						
CE9. Turkeys sleep inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE10. Guinea pigs spend time outside near the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE11. Guinea pigs enter the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE12. Guinea pigs sleep inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE16. Pigs spend time outside near the house	283 (95.3)	0 (0.0)	1 (0.3)	13 (4.4)	21.8	1.0
CE17. Pigs enter the house	296 (99.7)	0 (0.0)	0 (0.0)	1 (0.3)	296.0	0.7
CE18. Pigs sleep inside the house	296 (99.7)	0 (0.0)	0 (0.0)	1 (0.3)	296.0	0.7
CE19. Cattle spend time outside near the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE20. Cattle enter the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE21. Cattle sleep inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE23. Dairy cattle enter the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE24. Dairy cattle sleep in the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE25. Horses/mules/donkeys spend time outside near the house	294 (99.0)	0 (0.0)	0 (0.0)	3 (1.0)	98.0	0.7
CE26. Horses/mules/donkeys enter the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE27. Horses/mules/donkeys sleep inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE28. Sheep/goats spend time outside near the house	296 (99.7)	0 (0.0)	1 (0.3)	0 (0.0)	296.0	0.7
CE29. Sheep/goats enter the house	296 (99.7)	0 (0.0)	1 (0.3)	0 (0.0)	296.0	0.7
CE30. Sheep/goats sleep inside the house	296 (99.7)	0 (0.0)	1 (0.3)	0 (0.0)	296.0	0.7
CE34. Creole chickens sleep inside the house	290 (97.6)	1 (0.3)	1 (0.3)	5 (1.7)	58.0	1.3
CE37. Bushrats spend time outside near the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE38. Bushrats enter the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE39. Bushrats sleep inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE40. Rats/rodents spend time outside near the house	289 (97.3)	4 (1.3)	4 (1.3)	0 (0.0)	72.3	1.0
CE41. Rats/rodents enter the house	289 (97.3)	1 (0.3)	5 (1.7)	2 (0.7)	57.8	1.3
CE42. Rats/rodents sleep inside the house	289 (97.3)	0 (0.0)	6 (2.0)	2 (0.7)	48.2	1.0
CE43. Rabbits spend time outside near the house	292 (98.3)	1 (0.3)	0 (0.0)	4 (1.3)	73.0	1.0

Sub-domain and associated survey items	Frequency (%)					
	Never	Rarely	Sometimes	Frequently	Frequency ratio	Percent unique data points
***Child Environment (CE)* – Deleted items**						
CE44. Rabbits enter the house	291 (98.0)	0 (0.0)	0 (0.0)	6 (2.0)	48.5	0.7
CE45. Rabbits sleep inside the house	291 (98.0)	0 (0.0)	0 (0.0)	6 (2.0)	48.5	0.7
CE46. Production chicken poop outside the house near or in the yard	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE47. Production chicken poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE48. Duck poop outside the house near or in the yard	296 (99.7)	0 (0.0)	0 (0.0)	1 (0.3)	296.0	0.7
CE49. Duck poop inside the house	296 (99.7)	1 (0.3)	0 (0.0)	0 (0.0)	296.0	0.7
CE50. Turkey poop outside the house near or in the yard	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE51. Turkey poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.36
CE52. Guinea pig poop outside the house near or in the yard	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE53. Guinea pig poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.36
CE55. Dog poop inside the house	283 (95.3)	2 (0.7)	5 (1.7)	7 (2.4)	40.4	1.3
CE56. Pig poop outside the house near or in the yard	295 (99.3)	0 (0.0)	1 (0.3)	1 (0.3)	295.0	1.0
CE57. Pig poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE58. Cattle poop outside the house near or in the yard	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE59. Cattle poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE61. Dairy cattle poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.36
CE62. Horses/mule/donkey poop outside the house near or in the yard	293 (98.7)	0 (0.0)	0 (0.0)	4 (1.3)	73.3	0.7
CE63. Horses/mule/donkey poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE64. Sheep/goat poop outside the house near or in the yard	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE65. Sheep/goat poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE67. Cat poop inside the house	293 (98.7)	1 (0.3)	0 (0.0)	3 (1.0)	97.7	1.0
CE70. Bushrat poop outside the house near or in the yard	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE71. Bushrat poop inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE72. Rat/rodent poop outside the house near or in the yard	293 (98.7)	1 (0.3)	1 (0.3)	2 (0.7)	146.5	1.3
CE73. Rat/rodent poop inside the house	293 (98.7)	0 (0.0)	3 (1.0)	1 (0.3)	97.7	1.0

Sub-domain and associated survey items	Frequency (%) Never	Rarely	Sometimes	Frequently	Frequency ratio	Percent unique data points
***Child Environment (CE)* – Deleted items**						
CE74. Rabbit poop outside the house near or in the yard	296 (99.7)	0 (0.0)	0 (0.0)	1 (0.3)	296.0	0.7
CE75. Rabbit poop inside the house	296 (99.7)	0 (0.0)	1 (0.3)	0 (0.0)	296.0	0.7
CE76. Poop from an unknown type of animal outside the house near or in the yard	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE77. Poop from an unknown type of animal inside the house	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3
CE91. Mother or someone who lives in the same house puts or throws leftover food outside for an animal	175 (58.9)	17 (5.7)	29 (9.8)	76 (25.6)	2.3	1.3
CE96. Mother personally cares for an animal that was sick	285 (96.0)	3 (1.0)	1 (0.3)	8 (2.7)	35.6	1.3
***Child Behavior (CB)* – Deleted items**						
CB78. Child plays on the floor of the house without a rug or playmat	25 (8.4)	6 (2.0)	18 (6.1)	248 (83.5)	9.9	1.3
CB79. Child plays inside the house in an area where an animal spends time or sleeps	169 (56.9)	16 (5.4)	25 (.84)	87 (29.3)	1.9	1.3
CB82. Child plays in sand outside the house	60 (20.2)	27 (9.1)	35 (11.8)	175 (58.9)	2.9	1.3
CB88. Child puts sand in their mouth	244 (82.2)	11 (3.7)	7 (2.4)	35 (11.8)	7.0	1.3
CB103. Child touches or plays with objects used to remove or clean animal poop such as brooms or shovels	272 (91.6)	3 (1.0)	12 (4.0)	10 (3.4)	22.7	1.3
CB105. Child puts animal poop in their mouth	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0	0.3

Table S 7. Descriptive statistics for most common existing measures of exposure to zoonotic enteric pathogens (*n*=297)

Characteristics	Total		Rural river		River road		Semi-rural		Urban	
	n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
Number of participants	297		46	(15.4)	76	(25.6)	98	(33.0)	77	(25.9)
Owns animal(s)	165	(55.6)	22	(47.8)	48	(63.2)	61	(62.2)	34	(44.2)
Presence of animals	290	(97.6)	46	(100.0)	75	(98.7)	98	(100.0)	71	(92.2)
Presence of animal feces	210	(70.7)	38	(82.6)	44	(57.9)	79	(80.6)	49	(63.6)

Figure S 2. Correlation plot between child behavior and child environment sub-domain scores (*n*=297)

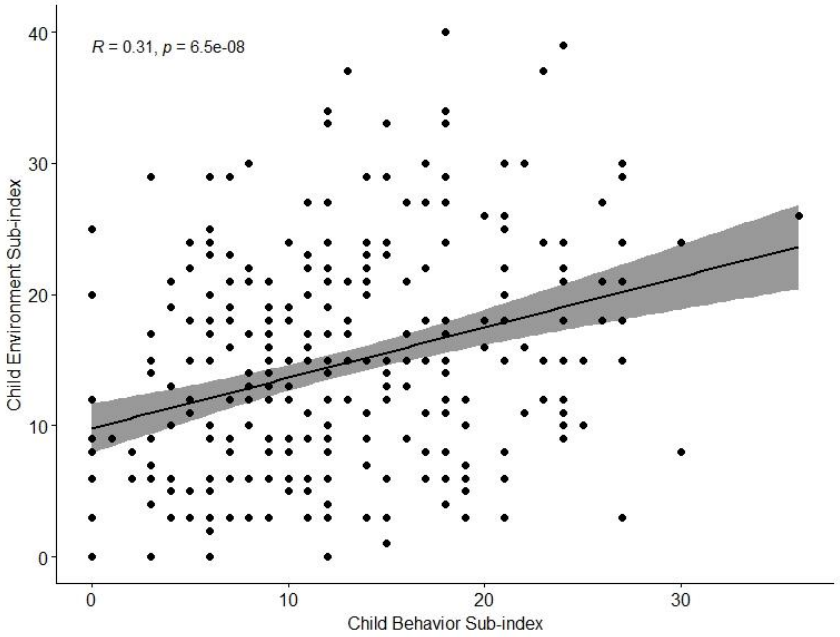

Figure S 3. Histogram of child environment sub-domain scores (possible score range: 0-60, *n*=297)

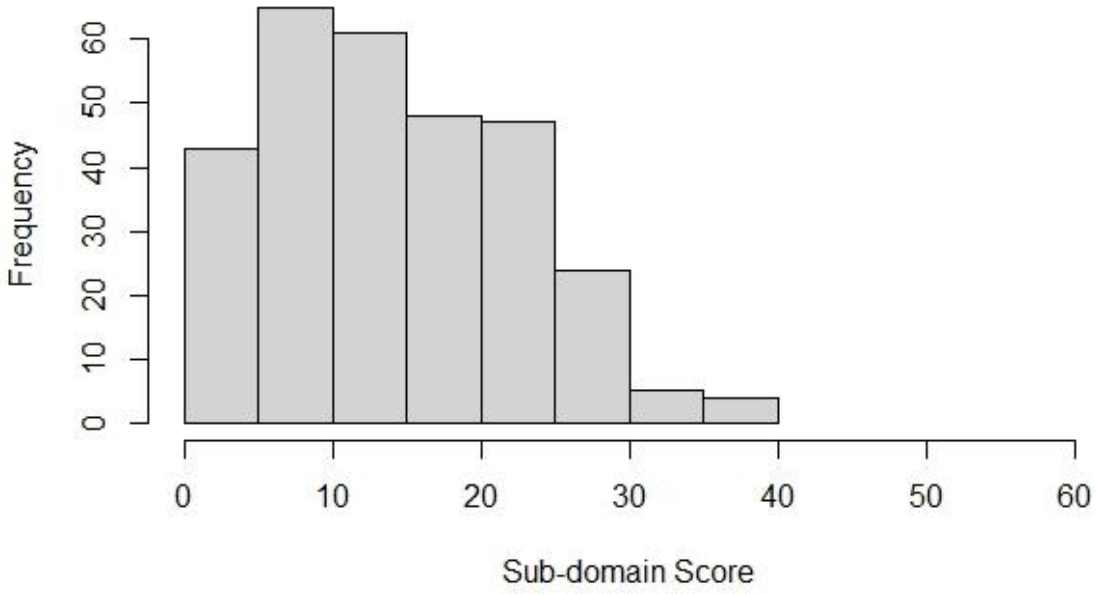

Figure S 4. Histogram of child behavior sub-domain scores (possible score range: 0-42, *n*=297)

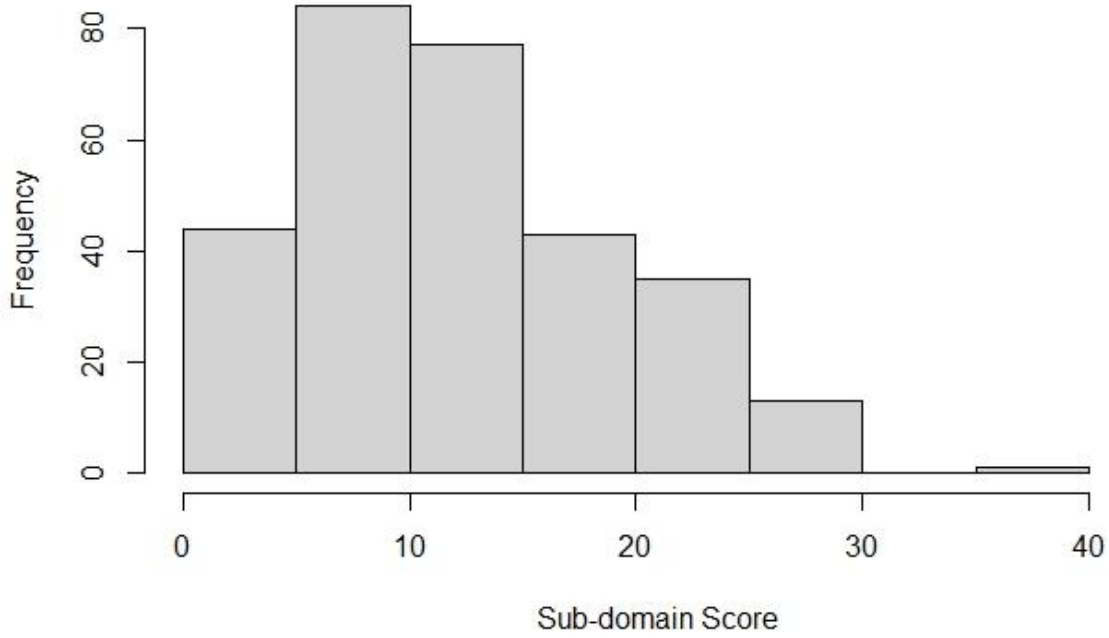

Figure S 5. Histogram of overall FECEZ enteropathogens index scores (possible score range: 0-102; *n*=297)