Full Title: Household Flooring Associated with Reduced Infant Diarrheal Illness in Zimbabwe in Households with and without WASH interventions

Short Title: Household Flooring and Infant Diarrheal Illness

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ABSTRACT

Objectives: Diarrheal illness is a leading cause of childhood morbidity and mortality and has long-term negative impacts on child development. Although flooring, water, and sanitation have been identified as important routes of transmission of diarrheal pathogens, research examining variability in the association between flooring and diarrheal illness by water and sanitation is limited.

Methods: We utilized cross-sectional data collected for the evaluation of Zimbabwe's Prevention of Mother-to-Child HIV transmission program in 2014 and 2017-18. Mothers of infants 9-18 months of age self-reported the household's source of drinking water and type of sanitation facility, as well as infant diarrheal illness in the four-weeks prior to the survey. Household flooring was assessed using interviewer observation, and households in which the main material of flooring was dirt/earthen were classified as having unimproved flooring and those with solid flooring (e.g. cement) were classified as having improved flooring.

Results: Mothers of infants living in households with improved flooring were less likely to report diarrheal illness in the last four weeks (PD_a=-4.9%, 95%CI: -8.6, -1.0). The association between flooring and diarrheal illness did not vary by the presence of improved/unimproved water (p_{RERI}=0.91) or sanitation (p_{RERI}=0.76).

Conclusions: Our findings support the hypothesis that household flooring is an important pathway for the transmission of diarrheal pathogens, even in settings where other aspects of sanitation are sub-optimal. Improvements to household flooring do not require behavior change and may be an effective and expeditious strategy for reducing childhood diarrheal illness irrespective of household access to improved water and sanitation.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

INTRODUCTION

Globally, diarrheal illness kills more children each year than malaria, measles, and AIDS combined, resulting in the death of over 1,000 children per day in 2017 (1). Children with diarrhea are at risk of mortality due to severe dehydration and are also more likely to suffer from malnutrition, impaired growth, and poor cognitive development than healthy children (2,3). The global burden of disease attributable to diarrhea is concentrated in sub-Saharan Africa and south-east Asia, where more than 80% of deaths due to diarrheal disease among children under-five occur (4).

An individual's risk of diarrheal illness is largely a function of their contact with human faeces, with approximately 60% of mortality associated with diarrheal illness attributable to inadequate access to safe drinking water, sanitation, and hygiene (WASH) (5). In addition to WASH, household flooring has been identified as a modifiable risk factor associated with infant diarrheal illness. Faecal pathogens are more likely to be present in households with dirt floors compared to those with solid floors due to difficulties disinfecting and removing environmental contaminants brought into homes by dirty shoes or feet, spillage of contaminated water, or through animals (6–8). In turn, children living in households without solid flooring who play and crawl on dirt floors are at a greater risk of ingesting faecal contaminants than children living households with solid flooring (6,8–10).

In 2009, a World Bank impact evaluation of government programs in Mexico which replaced dirt floors with cement in urban slums found significant reductions in incidence of parasitic infestations and episodes of infant diarrheal illness, as well as reductions in anemia and maternal depression (11). Despite providing rigorous evidence of the protective effect of solid flooring on incidence of infant diarrheal illness in urban slums, these findings may have limited generalizability to other settings and countries, such as Zimbabwe, in which the majority of the total population lives in rural areas with comparatively limited access to safe municipal water supplies and sanitation infrastructure (12,13). It is possible that the addition of solid flooring may not confer protection against diarrheal illness in rural settings where exposure to faecal pathogens persists from unsafe WASH. Although the few observational studies conducted to date including rural populations have supported the hypothesis that dirt/earthen flooring may increase risk of diarrheal illness compared to cement flooring (14–16), no studies have examined whether the potential protective effects of flooring improvements are differential by the presence of additional household improvements (i.e. WASH) that block other possible transmission routes for faecal pathogens.

In Zimbabwe, diarrheal illness remains a substantial barrier to improving child health and is a leading cause of under-5 morbidity and mortality (17). The objectives of this study are to: 1) examine the individual relationship between household flooring and infant diarrheal illness in Zimbabwe; and to 2) assess whether the association between household flooring and infant diarrheal illness is modified by existing improvements in household water or sanitation.

METHODS

This analysis utilizes data from two cross-sectional serosurveys of mother/caregiver-infant pairs conducted as part of the impact evaluation of Zimbabwe's Accelerated National Prevention-of-Mother-to-Child HIV Transmission (PMTCT) Program (hereafter the "parent study"). The aim of the parent study (ClinicalTrials.gov NCT03388398) was to assess the population level impact of the Accelerated PMTCT Program on HIV-free infant survival and mother-to-child HIV transmission (MTCT) in Zimbabwe (18). Three cross-sectional serosurveys of mother/caregiver-infant pairs were conducted in 2012, 2014, and 2017-18 to evaluate program impact before and after program implementation (18). In the 2014 and 2017-18 survey rounds, data were collected on infant diarrheal illness and household flooring, water, and sanitation; these survey years were pooled for this secondary analysis.

Study Population

The study population consisted of infants born 9-18 months prior to the survey who were alive at the time of the survey and their mothers or caregivers (≥16 years old) living in five of Zimbabwe's ten provinces. The five provinces (Harare, Mashonaland West, Mashonaland Central, Manicaland, and Matabeleland South) were purposefully selected to include urban and rural populations with higher and lower prevalences of HIV infection, and both Shona and Ndebele ethnic groups (18). For this analysis, the sample was restricted to 13,639 mothers/caregivers and their alive infants living in rural areas and excluded 4,477 mother-infant pairs living in urban areas, 184 mother-infant pairs in which the infant was deceased at the time of the survey, and 56 mother-infant pairs with missing values for the exposure, outcome, or covariates of interest.

Sampling Strategy

Mother-infant pairs were sampled using multi-stage sampling. In the first stage, 157 health facilities were randomly selected from 699 health facilities offering PMTCT services in each of the five selected provinces, proportionate to the number of facilities in each district (18). The catchment area (CA) of each selected health facility, which is a geographical area defined by Zimbabwe's Ministry of Health and Child Care, was used as the primary sampling unit. Random sampling of health facilities and their respective catchment areas only occurred once in the parent study, resulting in the same primary sampling units for all survey rounds.

The procedures for the second stage of sampling differed slightly in the 2014 and 2018 survey rounds. For the cross-sectional survey conducted in 2014, eligible infants were identified by pooling information from 1) village health workers (VHWs), 2) immunization registers from the selected health facilities and their neighboring facilities, and 3) mothers identified using VHWs and immunization registers that identified other eligible infants in their neighborhood (18). In the final stage of sampling eligible infants were randomly selected based on pre-determined sampling fractions proportionate to the size of the CA.

In 2018 these procedures were modified to increase the rigor of sampling methodology and move toward a community census-based approach. The second stage of sampling involved enumeration areas (geographic areas demarcated by the national census) falling within each clinic catchment area, which were enumerated and randomly selected using pre-determined sampling fractions. Eligible infants in each selected enumeration area within the clinic catchment area were identified by utilizing VHWs to perform a full census in each sampled enumeration area by screening all households within the enumeration area boundaries. In the final stage of sampling, all eligible infants living in each enumeration area were sampled. The sample size for the 2017-18 survey was calculated to allow detection of a 4% reduction from 2014 to 2017-18 in the primary outcomes of the impact evaluation, namely, MTCT and HIV-free infant survival.

Data Collection

Participating mothers and caregivers completed an interviewer-administered questionnaire capturing maternal and household demographics, information on the HIV status of the mother and infant, behaviors relevant to MTCT (e.g., health service utilization during pregnancy and after delivery, breastfeeding), household characteristics, and infant’s health status in the four weeks prior to the questionnaire (e.g., occurrence of diarrheal disease, fever). The main material of the household’s floor was determined by interviewer observation in the household while administering the questionnaire.

Study Indicators

Outcome: Infant Diarrheal Illness

Mothers/caregivers were asked whether their infants had at least one day of diarrheal illness in the four weeks prior to the interviewer-administered questionnaire, consistent with the standard WHO definition of >3 watery stools per day (19). A binary variable was used to indicate presence/absence of mother/caregiver-reported diarrheal illness in the prior four weeks among infants 9-18 months of age.

Primary Exposure: Household Flooring

Households in which the main material of flooring was solid, such as those with wood planks, parquet/polished wood, asphalt strips, ceramic tiles, cement, and carpet were classified as having improved flooring. Households without solid flooring, such as those with earth, sand, and dung were classified as having unimproved flooring.

Potential Effect Measure Modifiers: Household Water and Sanitation

Two factors were examined as potential effect measure modifiers of the association between household flooring and infant diarrheal illness. The self-reported main source of drinking water for members of the household was categorized as a binary variable indicating whether the source of water was improved or unimproved consistent with 2017 World Health Organization/United Nations Children's Fund standard categories for improved/unimproved water sources (20). Households in which the main source of water was from piped water on premises, public taps, tube wells/boreholes, protected wells, protected springs, bottled water, and rain water were classified as having improved water sources. Households in which the main source of water was from unprotected wells, unprotected springs, surface water, tanker trucks, carts, or other were classified as having unimproved water sources. Similarly, the self-reported type of sanitation facility used by each household was categorized as a binary variable indicative of whether the toilet facility adequately separates faecal matter from human contact consistent with categories established by WHO/UNICEF (20). Households with flush/pour toilets, ventilated improved pit latrines (VIP), and pit latrines with slabs that were not shared were classified as having improved sanitation facilities. Households with any type of shared facility, pit latrines without slabs, bucket latrines, and open defecation were categorized as having unimproved sanitation facilities.

Statistical analysis

The association between household flooring and infant diarrheal illness 9-18 months after birth was examined by using Poisson regression models with robust variance to predict unadjusted and adjusted absolute prevalence differences (PD) and corresponding 95% confidence intervals (21–23). Fully adjusted models contain all covariates specified *a priori* for inclusion via directed acyclic graph (DAG) based analysis as potential confounders, including: survey-round of data collection (2014 vs 2017-18), season of data collection (winter/dry season vs summer/rainy season), socioeconomic status, and residence in urban/rural health facility catchment areas. An index of household socioeconomic status was constructed using principle component analysis of household possessions (i.e. television, radio, car, livestock). Variance inflation factors (VIFs) were examined to test for the presence of multicollinearity in the fully adjusted model, and covariates with VIFs ≥10 (severe collinearity) were excluded if necessary (24). Sensitivity analysis was conducted using inverse probability of treatment weighting (IPTW) to adjust for possible unmeasured confounding and measure the population average treatment effect on the treated (PATT) (25). Survey sampling weights were used in addition to all covariates specified *a priori* for inclusion in adjusted models to estimate propensity scores (25). A logit model was used to split the sample into equally spaced intervals until the average propensity score did not differ between individuals with/without improved flooring in each interval and subsequently verify that observations with the same propensity score had similar distributions of *a priori* specified observed covariates (26).

To assess whether the association between household flooring and infant diarrheal illness varied based on household water and sanitation, separate models were built with main effects for flooring and WASH plus interaction terms between household water/flooring and household sanitation/flooring, respectively. All *a priori* covariates specified as potential confounders of the relationship between the exposure and infant diarrheal illness were included in the adjusted models. The presence of effect measure modification on the additive scale was examined using relative excess risk due to interaction (RERI) evaluated at an alpha significance level of $P < 0.20$ (27,28).

All analyses were weighted to account for varying sampling fractions by catchment area and linearized standard errors were utilized to account for these design features (18). Statistical significance for all parameter estimates was evaluated at the alpha significance level of $P < 0.05$. All analyses were conducted with STATA 15 (College Station, Texas).

Ethics

The impact evaluation of Zimbabwe's Accelerated National PMTCT Program used for this analysis was approved by the Medical Research Council of Zimbabwe and the ethical review boards at the University of California, Berkeley, University College London, and Liverpool School of Tropical Medicine.

RESULTS

The weighted study population included 10,807 mother-infant pairs (based on 13,639 observations; Table 1). Overall, 51% of study participants were living in households with improved flooring. The likelihood of having improved floors increased among households with higher SES quartile (86.3% in Q4 vs 49.5% in Q1), access to improved water (71.8% vs 52.5%), and access to improved sanitation (80.5% vs 47.0%).

Improved Flooring and Infant Diarrheal Illness

The prevalence of infant diarrheal illness among all study participants was 32.4%, with approximately 28.7% of mothers/caregivers in households with improved flooring reporting infant diarrheal illness and 34.8% of mothers/caregivers in households with unimproved flooring reporting infant diarrheal illness (PD= -6.1%, 95%CI: -9.2, -3.1, Table II). The magnitude of the association between improved flooring and diarrheal illness in the last four weeks slightly decreased after adjustment for potential confounders (PD_a=-4.8%, 95%CI: -8.6, -1.0). Sensitivity analysis incorporating IPTW weighting yielded similar results suggestive of a protective association between improved flooring and infant diarrheal illness (PATT=-5.6%, 95%CI: -9.0, -2.2). The protective association identified between household flooring and diarrheal illness did not change after exclusion participants who self-reported possible participation in both survey rounds (N=393).

Effect Measure Modification by Household Water and Sanitation

There was no variation in the strength of the association between household flooring and infant diarrheal illness between groups stratified by whether household water or sanitation was also available (Figure I & Table III). Specifically, the association between household flooring and infant diarrheal illness was not modified by household water (p_{RERI}= 0.91) or sanitation (p_{RERI}= 0.76) on the additive scale.

DISCUSSION

In this large sample of mother/caregiver-infant pairs living in rural areas of five of Zimbabwe's ten provinces, caregivers of infants living in homes with improved flooring were significantly less likely to report infant diarrheal illness in the last 4 weeks compared to those in households with unimproved flooring. Results suggestive of a protective association between improved flooring and infant diarrheal illness were also found in sensitivity analysis incorporating more robust IPTW analytic methodology. In addition, the strength of the protective association between household flooring and infant diarrheal illness was consistent irrespective of whether households also had access to safe water/sanitation. We provide the first estimates, to our knowledge, that examine heterogeneity in the association between household flooring and infant diarrheal illness by concurrent WASH interventions, and suggest that improved household flooring confers protection against diarrheal illness regardless of the quality of a household's water or sanitation.

Our findings of a protective association between improved household flooring and infant diarrheal illness are consistent with existing literature examining the positive health effects of improved household flooring (11,14,15)01-01-0001 05:30:00. Recently, the Sanitation, Hygiene, Infant Nutrition Efficacy (SHINE) trial in Zimbabwe found no effect of WASH interventions combined with the provision of plastic play mats/spaces on childhood diarrheal disease (29). The investigators note, however, that 27% of mothers who received solid play mats/spaces still reported observing geophagia among their infants at the 12-month study visit (29). Given the prevalence of oral exploration during early childhood development (10,30) , we hypothesize that there may be a minimum required coverage of improved flooring within a household in order to significantly reduce childhood exposure to diarrheal pathogens.

When considered in the context of the substantial burden of childhood diarrheal illness in Zimbabwe, the magnitude of the association between household flooring and infant diarrheal illness found in our analysis (PD_a=-4.8%) suggests that improvements in flooring have the potential to significantly improve child health. Additionally, our effect heterogeneity results suggest that improved flooring confers protection against diarrheal illness irrespective of household water and sanitation. These findings underscore the premise that household flooring is an important pathway for transmission of faecal pathogens, and suggest that improving flooring quality could reduce diarrheal illness even when exposure to faecal pathogens persists from contaminated water sources or sanitation facilities.

While over half of deaths due to diarrheal disease are attributable to inadequate WASH, population-level improvements in child health achieved through increasing coverage of safe WASH require broad scale infrastructural changes that often take place over decades, supplemented by sustained individual level behavior change (5,12,31–33). Disparities between the substantial financial investments needed to expand WASH infrastructure and available funds in countries such as Zimbabwe in turn precludes progress towards achieving the Sustainable Development Goal (SDG) of universal access to safe water and sanitation by 2030 (12,34). In contrast, households often independently invest in housing improvements irrespective of potential health benefits. Furthermore, recent experimental trials from Zimbabwe and Kenya suggest that household level WASH interventions may not be sufficient on their own to protect against diarrheal illness (29,33,35). Additional experimental research is critically needed to evaluate whether flooring improvements, in combination with WASH and nutritional interventions, may be necessary to intervene on diarrheal disease in settings with high childhood exposure to faecal contaminants (33,36). While public health programs continue working towards improving WASH capacity in developing countries, interventions aimed at providing improved flooring and/or expediting families' investment in improved household flooring (e.g. housing microfinance) may offer an expedient strategy to intervene on early childhood diarrheal disease that does not necessitate individual behavior change.

Limitations

This analysis has several limitations. We utilized data from cross-sectional serosurveys, and thus cannot make causal claims regarding the relationship between improved flooring, water, and sanitation and infant diarrheal illness. As with all observational studies, our analyses are potentially susceptible to unmeasured confounding. For example, coverage of improved flooring in community spaces in which children play could influence both a child's likelihood of living in a home with improved flooring as well as their likelihood of diarrhea. To mitigate differences in our exposure groups, we used IPTW to balance the groups on factors which influenced our exposure of interest and make more comparable groups in which the relationship between treatment and measured confounders is removed (25), which can also increase the balance in unmeasured confounders.

Self-report of infant diarrheal illness in the 4 weeks prior to the survey by mothers/caregivers in this study increases the possibility of information bias due to misclassification of the outcome. If misclassification of infant diarrheal illness occurred non-differentially due to poor recall or social desirability bias among all participants regardless of flooring, we expect the association between household flooring and infant diarrheal illness to be underestimated in our analysis. Alternatively, underreporting of diarrheal illness due to social desirability bias may have occurred differentially, with wealthier households less likely to report diarrheal illness potentially resulting in overestimated prevalence differences in our analysis. It is also plausible that mothers/caregivers in households with unimproved flooring may have been more likely to over-report diarrheal illness due to hopes for humanitarian assistance, which would in turn bias our estimated prevalence differences away from the null. Despite this, our use of self-report to measure infant morbidity associated diarrheal illness remains consistent with the preponderance of existing evaluations of the impact of household flooring, water, and sanitation on infant diarrhea as well as most epidemiologic studies of diarrheal disease (37,38). Misclassification of household WASH may also have occurred due to utilization of binary WHO/UNICEF established categories of improved/unimproved water and sanitation. Although WHO/UNICEF standard categories were designed to be scalable metrics that increase the consistency of WASH evaluations around the world, household water/sanitation that is categorized as being "improved" by WHO/UNICEF may not necessarily adequately separate water from faecal contamination in all country specific settings (39). For example, evaluations of water infrastructure in Zimbabwe suggest prevalent contamination of water sources, such as boreholes, that are typically classified as improved water sources (40,41). Longitudinal evaluations that have greater specificity of measurements for outcomes and potential effect modifiers of interest (e.g. measurement of faecal contaminants in water sources) are thus needed to confirm the findings of this analysis.

Although the sampling frame of mother/caregiver-infant pairs in the parent study was rigorously established using community based and health facility-based strategies, some mother-infant pairs, such as those among migrant populations, may have been systematically excluded from this analysis. Finally, although our sample of mother-infant pairs excluded deceased infants and therefore possibly excluded deaths due diarrheal disease, the prevalence of mother/infant pairs with deceased infants was similar between improved/unimproved flooring groups (Chi-squared p=0.53).

CONCLUSION

This analysis is the first to our knowledge to evaluate variation in the association between household flooring and infant diarrheal illness controlling for household water and sanitation. In a sample of mother/caregiver-infant pairs in living in five of Zimbabwe's ten provinces, improved flooring was inversely associated with likelihood of infant diarrheal illness. Homogeneity in the protective association between improved household flooring and diarrheal illness in subgroups defined by access to safe water and sanitation suggests that household flooring interventions may be used to reduce the prevalence of early childhood diarrheal disease even in setting with unimproved water/sanitation.

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REFERENCES

1. Roth GA, Abate D, Abate KH, Abay SM, Abbafati C, Abbasi N, 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 Nov 10;392(10159):1736–88.

2. Global Diarrhea Burden | Global Water, Sanitation and Hygiene | Healthy Water | CDC [Internet]. 2018 [cited 2020 Jan 25]. Available from: https://www.cdc.gov/healthywater/global/diarrhea-burden.html

3. Bowen A, Agboatwalla M, Luby S, Tobery T, Ayers T, Hoekstra RM. Association between intensive handwashing promotion and child development in Karachi, Pakistan: a cluster randomized controlled trial. Arch Pediatr Adolesc Med. 2012 Nov;166(11):1037–44.

4. Children: reducing mortality [Internet]. [cited 2019 Nov 17]. Available from: https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality

5. Prüss-Ustün A, Wolf J, Bartram J, Clasen T, Cumming O, Freeman MC, 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. Int J Hyg Environ Health. 2019 Jun;222(5):765–77.

6. Exum NG, Olórtegui MP, Yori PP, Davis MF, Heaney CD, Kosek M, et al. Floors and toilets: Association of floors and sanitation practices with fecal contamination in Peruvian Amazon peri-urban households. Environ Sci Technol. 2016 Jul 19;50(14):7373–81.

7. Pickering AJ, Julian TR, Marks SJ, Mattioli MC, Boehm AB, Schwab KJ, et al. Fecal contamination and diarrheal pathogens on surfaces and in soils among Tanzanian households with and without improved sanitation. Environ Sci Technol. 2012 Jun 5;46(11):5736–43.

8. Ercumen A, Pickering AJ, Kwong LH, Arnold BF, Parvez SM, Alam M, et al. Animal Feces Contribute to Domestic Fecal Contamination: Evidence from E. coli Measured in Water, Hands, Food, Flies, and Soil in Bangladesh. Environ Sci Technol. 2017 Aug 1;51(15):8725–34.

9. Teunis PFM, Reese HE, Null C, Yakubu H, Moe CL. Quantifying Contact with the Environment: Behaviors of Young Children in Accra, Ghana. Am J Trop Med Hyg. 2016 Apr 6;94(4):920–31.

10. Wang Y, Moe CL, Null C, Raj SJ, Baker KK, Robb KA, et al. Multipathway Quantitative Assessment of Exposure to Fecal Contamination for Young Children in Low-Income Urban Environments in Accra, Ghana: The SaniPath Analytical Approach. Am J Trop Med Hyg. 2017 Oct 11;97(4):1009–19.

11. Cattaneo MD, Galiani S, Gertler PJ, Martinez S, Titiunik R. Housing, Health, and Happiness. American Economic Journal: Economic Policy. 2009 Jan;1(1):75–105.

12. World Bank. Water supply and sanitation in Zimbabwe : turning finance into services for 2015 and beyond (English). An AMCOW country status overview; Water and sanitation program [Internet]. Washington DC: World Bank Group; 2011. Available from: http://documents.worldbank.org/curated/en/338521468336005540/Water-supply-and-sanitation-in-Zimbabwe-turning-finance-into-services-for-2015-and-beyond

13. Rural population (% of total population) | Data [Internet]. [cited 2020 Jan 25]. Available from: https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS

14. Hbatu M, Nsabimana J, Mureithi C. Factors Contributing to Diarrheal Diseases among Children Less than Five Years in Nyarugenge District, Rwanda. J Trop Dis [Internet]. 2017 [cited 2020 Jan 25];05(03). Available from: https://www.omicsonline.org/open-access/factors-contributing-

to-diarrheal-diseases-among-children-less-than-fiveyears-in-nyarugenge-district-rwanda-2329-891X-1000238.php?aid=90998

15. Factors Associated with Diarrhoea Prevalence in Saudi Arabia [Internet]. [cited 2020 Jan 25]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3437149/

16. Yaya S, Hudani A, Udenigwe O, Shah V, Ekholuenetale M, Bishwajit G. Improving Water, Sanitation and Hygiene Practices, and Housing Quality to Prevent Diarrhea among Under-Five Children in Nigeria. Trop Med Infect Dis [Internet]. 2018 Apr 12 [cited 2020 Jan 26];3(2). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6073794/

17. Ministry of Health and Child Welfare. The National Child Survival Strategy for Zimbabwe 2010-2015.

18. Buzdugan R, McCoy SI, Watadzaushe C, Kang Dufour M-S, Petersen M, Dirawo J, et al. Evaluating the Impact of Zimbabwe's Prevention of Mother-to-Child HIV Transmission Program: Population-Level Estimates of HIV-Free Infant Survival Pre-Option A. PLoS One [Internet]. 2015 Aug 6 [cited 2020 Jan 25];10(8). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4527770/

19. Diarrhoeal disease [Internet]. [cited 2020 Jan 25]. Available from: https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease

20. Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF); 2017.

21. Thompson ML, Myers JE, Kriebel D. Prevalence odds ratio or prevalence ratio in the analysis of cross sectional data: what is to be done? Occup Environ Med. 1998 Apr;55(4):272–7.

22. Alternatives for logistic regression in cross-sectional studies: an empirical comparison of models that directly estimate the prevalence ratio [Internet]. [cited 2020 Jan 25]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC521200/

23. Coutinho LMS, Scazufca M, Menezes PR. Methods for estimating prevalence ratios in cross-sectional studies. Revista de Saúde Pública. 2008 Dec;42(6):992–8.

24. Regression with Stata Chapter 2 – Regression Diagnostics [Internet]. [cited 2020 Jan 25]. Available from: https://stats.idre.ucla.edu/stata/webbooks/reg/chapter2/stata-webbooksregressionwith-statachapter-2-regression-diagnostics/

25. DuGoff EH, Schuler M, Stuart EA. Generalizing Observational Study Results: Applying Propensity Score Methods to Complex Surveys. Health Serv Res. 2014 Feb;49(1):284–303.

26. Becker SO, Ichino A. Estimation of Average Treatment Effects Based on Propensity Scores. The Stata Journal. 2002 Dec;2(4):358–77.

27. Marshall SW. Power for tests of interaction: effect of raising the Type I error rate. Epidemiol Perspect Innov. 2007 Jun 19;4:4.

28. Selvin S. Statistical Analysis of Epidemiologic Data. Oxford University Press; 2004.

29. Prendergast AJ, Chasekwa B, Evans C, Mutasa K, Mbuya MNN, Stoltzfus RJ, et al. Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on stunting and anaemia among HIV-exposed children in rural Zimbabwe: a cluster-randomised controlled trial. The Lancet Child & Adolescent Health. 2019 Feb 1;3(2):77–90.

30. Ngure FM, Humphrey JH, Mbuya MNN, Majo F, Mutasa K, Govha M, et al. Formative Research on Hygiene Behaviors and Geophagy among Infants and Young Children and Implications of Exposure to Fecal Bacteria. Am J Trop Med Hyg. 2013 Oct 9;89(4):709–16.

31. Kelly MP, Barker M. Why is changing health-related behaviour so difficult? Public Health. 2016 Jul;136:109–16.

32. Durrans S. Behaviour Change for Water, Sanitation and Hygiene [Internet]. 2018 Jun. Available from:

https://www.pseau.org/outils/ouvrages/share_behaviour_change_for_wash_policy_brief_2018.pdf

33. Cumming O, Arnold BF, Ban R, Clasen T, Esteves Mills J, Freeman MC, 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 Aug 28;17(1):173.

34. Water and Sanitation - United Nations Sustainable Development [Internet]. [cited 2020 Jan 25]. Available from: https://www.un.org/sustainabledevelopment/water-and-sanitation/

35. Null C, Stewart CP, Pickering AJ, Dentz HN, Arnold BF, Arnold CD, et al. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. Lancet Glob Health. 2018;6(3):e316–29.

36. Wilson-Jones M, Smith K, Jones D, Hamilton H, Richardson L, Macintyre A, et al. Response to 'The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement' by Cumming et al. BMC Med. 2019 Sep 26;17(1):183.

37. Evidence on the Effectiveness of Water, Sanitation, and Hygiene (WASH) Interventions on Health Outcomes in Humanitarian Crises: A Systematic Review [Internet]. [cited 2020 Jan 25]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4580573/

38. Schmidt W-P, Arnold BF, Boisson S, Genser B, Luby SP, Barreto ML, et al. Epidemiological methods in diarrhoea studies--an update. Int J Epidemiol. 2011 Dec;40(6):1678–92.

39. Shaheed A, Orgill J, Montgomery MA, Jeuland MA, Brown J. Why "improved" water sources are not always safe. Bull World Health Organ. 2014 Apr 1;92(4):283–9.

40. The New Humanitarian | Old drains and dirty water: Zimbabwe's chronic cholera crisis [Internet]. [cited 2020 Jan 25]. Available from: http://www.thenewhumanitarian.org/news-feature/2018/11/02/old-drains-and-dirty-water-zimbabwe-s-chronic-cholera-crisis

41. Troubled Water: Burst Pipes, Contaminated Wells, and Open Defecation in Zimbabwe's Capital - Zimbabwe [Internet]. ReliefWeb. [cited 2020 Jan 25]. Available from: https://reliefweb.int/report/zimbabwe/troubled-water-burst-pipes-contaminated-wells-and-open-defecation-zimbabwe-s-capital

Table I: Sociodemographic characteristics of participants (weighted N and %), Zimbabwe, 2014-2018; Women were ≥16 years old and mothers/caregivers of infants born 9-18 months prior to the interview [A]

Characteristic	**Total (N=10,807)**	**Improved Flooring**	
		Yes (n=7,408)	**No (n=3,399)**
	N (column %)	**N (row %)**	**N (row %)**
Year of data collection			
2014	5,953 (55.1)	3,923 (65.9)	2,030 (34.1)
2017-18	4,853 (44.9)	3,485 (71.8)	1,369 (28.2)
Season of data collection			
Winter/Dry Season	5,740 (53.1)	3,876 (67.5)	1,864 (32.5)
Summer/Wet Season	5,066 (46.9)	3,532 (69.7)	1,535 (30.3)
Socioeconomic status (quartile) [B]			
1st (lowest)	2,772 (25.6)	1,373 (49.5)	1,399 (50.5)
2nd	2,812 (26.0)	1,800 (64.0)	1,011 (36.0)
3rd	2,607 (24.1)	1,976 (75.8)	631 (24.2)
4th (highest)	2,616 (24.2)	2,258 (86.3)	357 (13.7)
Household Water			
Unimproved	1,812 (16.8)	862 (52.5)	951 (47.5)
Improved	8,994 (83.2)	2,537 (71.8)	6,457 (28.2)
Household Sanitation			
Unimproved	3,862 (35.7)	1,815 (47.0)	2,047 (53.0)
Improved	6,944 (64.3)	5,592 (80.5)	1,352 (19.5)

[A] Weighted counts and proportions presented in the table

[B] Household socioeconomic index: quartiles from tetrachoric principle component analysis (PCA) of household possessions

Table II: Prevalence of infant diarrheal illness by household flooring

Household Flooring **Total (N=10,807)**	N	Diarrheal Illness [A] N (row %)	Crude PD % (95% CI)	Adjusted [B] PD % (95% CI)	PATT % (95% CI)
Unimproved Floor	3,399	1,184 (34.8)	Reference	Reference	Reference
Improved Floor	7,408	2,126 (28.7)	-6.1*** (-9.2, -3.1)	-4.8** (-8.6, -1.0)	-5.6 (-9.0, -2.2)

PD: Prevalence difference; PATT: Population average treatment effect on the treated; CI: Confidence interval

[A] Diarrheal illness defined as >3 watery stools per day

[B] Adjusted for round of data collection, season of data collection, socioeconomic status, and household water and sanitation

P-value: *p<0.20, **p<0.05, ***p<0.01

Table III: Association between household flooring and infant diarrheal illness stratified by household water and sanitation, Zimbabwe, 2014-2018

Total (N=10,807)	Household Flooring	N	Diarrheal Illness [A] N (row %)	Adjusted [B] PD % (95% CI)	RERI p-value
Unimproved Water	Unimproved Floor	862	299 (34.7)	Reference	0.91
	Improved Floor	951	272 (28.6)	-4.5 (-13.3, 4.1)	
Improved Water	Unimproved Floor	2,537	885 (34.9)	Reference	
	Improved Floor	6,457	1,854 (28.7)	-4.9*** (-8.2, -1.5)	
Unimproved Sanitation	Unimproved Floor	2,047	728 (35.6)	Reference	0.76
	Improved Floor	1,815	551 (30.4)	-5.1** (-9.6, -0.74)	
Improved Sanitation	Unimproved Floor	1,352	456 (33.7)	Reference	
	Improved Floor	5,592	1,574 (28.2)	-4.6** (-8.9, -0.24)	

PD: Prevalence difference; CI: Confidence interval

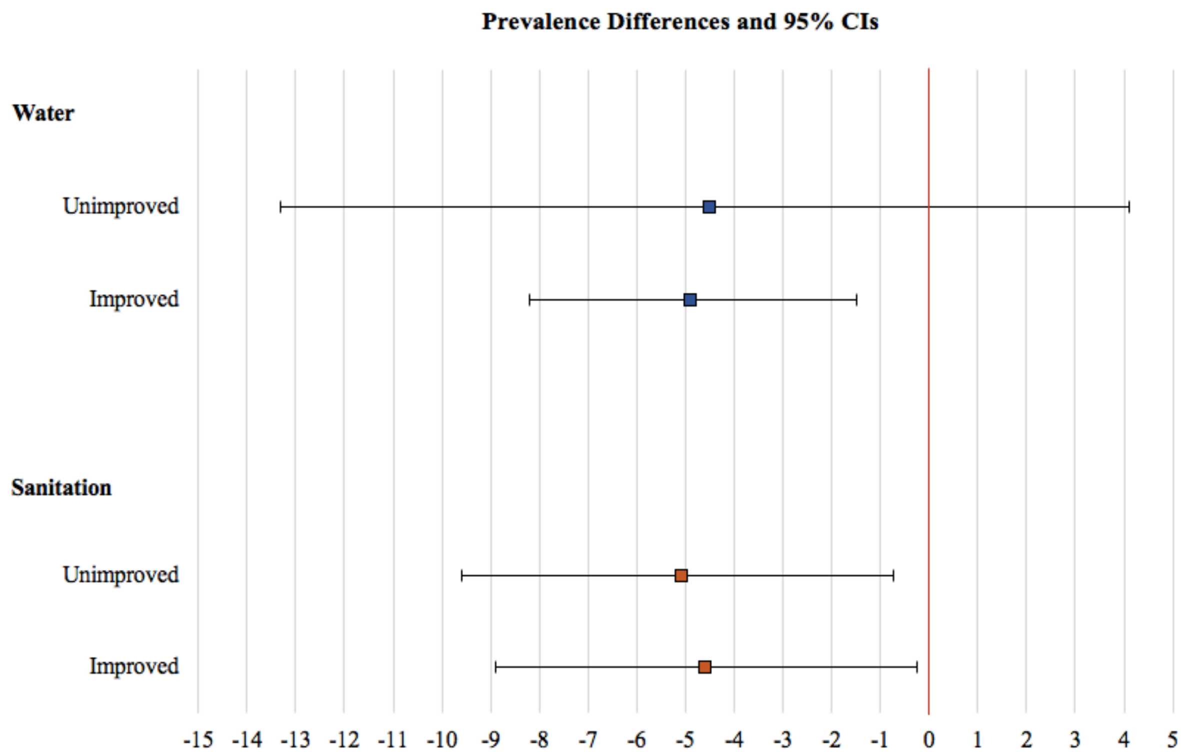
[A] Diarrheal illness defined as >3 watery stools per day

[B] Adjusted for round of data collection, season of data collection, socioeconomic status, and household water and sanitation.

CI: Confidence Interval

P-value: *p<0.20, **p<0.05, ***p<0.01

Figure I: Association between household flooring and infant diarrheal illness within groups defined by the presence of improved household water and sanitation, Zimbabwe, 2014-2018



CI: Confidence interval