Implications of latrine access on the improvement of linear childhood growth due to sanitation interventions in rural Kenya and Bangladesh

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Executive Summary

Background Diarrheal disease continues to disproportionately burden developing nations. The high prevalence of these preventable diseases is often attributed to poor water, sanitation, and hygiene (WASH) in affected communities. Diarrheal disease has been linked to linear growth faltering in children, but no previous studies have looking into the causal relationship between improved sanitation and increased length-for-age z-scores (LAZ)

Problem The external validity of a 2013 WASH Benefits study was called into question due to the preexisting improved latrines that existed in participating villages. The original findings concluded that sanitation interventions, both in isolation and in combination with other WASH and nutrition efforts, had no significantly impact on childhood growth. Arguments against the results were published, claiming that latrine status at enrollment reduced the potential impact that improved sanitation has on childhood growth.

Methods A reanalysis of data collected in the control group of the initial WASH Benefits will be completed. Calculations will be made to find the unadjusted and adjusted differences in LAZ between households that had improved latrines at baseline and households that did not have improved latrines at baseline

Results The mean LAX measurements were still low across the board after stratifying data for latrine status at enrollment. There were significantly significant LAZ differences in households with improved latrines at baseline relative to households that did not have improved latrines

Conclusion Children in households with improved sanitation structures still faced poor growth outcomes. Improved latrines did result in a significant improvement in mean LAZ, but many other determinants need to be considered in order to put LAZ measurements at a “healthy” level. Global sanitation efforts are still crucial to the development of equitable societies, even if there is not a strong link between improved sanitation and a reduction in childhood linear growth faltering.

Background

Diarrheal disease is the leading cause of death for children in the developing world, killing approximately 2,195 children each day. The high prevalence of these preventable diseases is widely attributed to poor hygienic practices and limited access to sanitation infrastructure – about 88% of diarrhea-associated deaths are due to inadequate water, sanitation, or hygiene. The United Nations reports that 3 in 10 people lack safely managed drinking water services, and 6 in 10 people lack access to safely managed sanitation facilities. Approximately 4 billion people lack access to toilets or latrines, and 1.7 billion people live in areas where water demand exceeds readily available supply.[1]

Published literature has reported an association between diarrheal infections and childhood growth faltering. Linear growth faltering is defined as an exceptionally slow rate of gain in height and has been linked to poor health outcomes later in life. Faltering is quantified by a length-for-age Z-score (LAZ) that measures a child’s growth relative to a standard distribution of a healthy population, as defined by the World Health Organization (WHO). Causal pathways are fairly unknown, as no randomized controlled trials have explored the causal relationship between diarrheal infections and linear growth faltering.[1,2]

Problem

In 2013, the Colford-Hubbard Research Group at the UC Berkeley School of Public Health published findings on a series of cluster-randomized trials on the individual and combined effects of WASH and nutritional interventions in rural areas of Kenya and Bangladesh. The longitudinal cohort study was the first comprehensive experiment to test if these interventions had an impact on the reduction of diarrhea or improvement of childhood growth. The results were disappointing – WASH interventions were not shown to improve either outcome of interest. Nutrition interventions helped slightly improve linear growth, but there were no additional improvements in combining WASH and nutrition interventions. Researchers hypothesized that the low impact of these interventions is due to the continued exposure of young children to animal feces.

In response to these findings, several members from the global health community have expressed concerns on the external validity of the study. They noted that the villages selected for the study already had access to improved water sources and relatively low levels of open defecation at baseline. They particularly emphasized that the existing presence of improved latrines may be confounding factors that dismiss the impact of sanitation on childhood growth and development.

To address these concerns, further analysis of the original study data is necessary. Measures of childhood growth should be evaluated with respect to latrine status at enrollment. This will determine if access to improved sanitation infrastructure had an influence on the efficacy of sanitation interventions on linear childhood growth in the WASH Benefits trials. [3, 4, 5]

Data

Similarly structured trials were conducted in rural villages of Kenya and Bangladesh that were selected for their high prevalence of diarrheal disease and linear growth faltering. These populations are representative of other rural areas in their respective countries

In the enrollment period of each study, pregnant women were block-randomized into one of the following treatment arms: chlorinated water, improved sanitation, promotion of handwashing, nutrition education plus lipid-based supplements, water plus sanitation plus handwashing, water plus sanitation plus handwashing plus nutrition, or control. Outcomes of the mothers and their young children were recorded at the one-year mark and two-year mark following the intervention.

For the purposes of this analysis, three datasets from each country will be used.

- Enrollment data: variables include demographic/socioeconomic status of household, height of parents, distance from water source, ownership of latrine/toilet, observations of feces in/around household, home infrastructure, household assets
    - Each row of the data represents one child in the study
        - Bangladesh: 5,551 observations, 73 variables
        - Kenya: 8,246 observations, 9 variables
- Treatment assignment data: variables include treatment assignment (study arm)
    - Each row represents one child (Bangladesh) or one block (Kenya) in the study
        - Bangladesh: 5,551 observations, 8 variables
        - Kenya: 702 observations, 3 variables
- Anthropometry data: variables include data/round of measurement, maternal weight, child sex, child weight, child length, child head circumference, child age, length/height-for-age Z-score (LAZ), head circumference-for-age Z-score
    - Each row of the data represents one observation for one child
        - Bangladesh: 9,342 observations, 46 variables
            - All collected observations included
        - Kenya: 7,240 observations, 59 variables
            - All observations collected at the two-year mark included

Data from each of the tables can be matched by compound ID, child ID, mother ID, cluster ID, and/or block ID. Some children were lost-to-follow up as a result of death - both at birth and during infancy - or relocation of family.

Length-for-age Z-scores (LAZ) were calculated using 2006 WHO child growth standards.

An improved latrine is defined to be either a latrine with a slab that follows WHO/UNICEF standards (Kenya) or a latrine with a working water seal (Bangladesh).

Analytical Methods

The methodology described in the following section outlines the replication process for an analysis originally completed by Ben Arnold. Arnold published the findings to address a response to the original WASH Benefits paper which claimed that high baseline latrines access undervalued the benefits of sanitation interventions on linear child growth after two years.

In this analysis, we will be observing the control and/or passive control arms of each trial. Only observations from the endline (two-years post-intervention) anthropometry data of each study will be used.

To determine the effect that baseline latrine ownership had on the length-for-age z score, we will estimate unadjusted and adjusted differences in mean LAZ between households that did not have an improved latrine at baseline and those that did. To interpret the results, a 95% confidence interval will be used, along with the p-value of the observed difference under the null hypothesis that there is no difference in mean LAZ between households with latrines and households without latrines.

Analysis Packages

The original analysis made use of an internal analysis package developed by researchers of the original WASH Benefits trials. The package contains functions to prescreen data for covariates, find the mean values of outcome data, permute data, and load publicly available datasets. The package also contains wrapper functions for the use of generalized linear models and targeted maximum likelihood estimators.

In this replication, analysis will be completed manually (without the washb package) with the exception of the application targeted maximum likelihood estimation to adjust for covariates in the calculation of LAZ differences between f

This analysis was completed in R-3.5.1. Dependencies for this analysis include the following R packages: SuperLearner, tmle, sandwich, lmtest, gam, splines, and glmnet.

Data Processing

In both countries, enrollment, treatment assignment, and anthropometry data were first merged into a single data table using a left-join on Data ID, Cluster ID, Block ID, and Treatment Assignment. The data was then filtered to rows that met the following three conditions:

- Observation block assigned to the control or passive control group
- Observation recorded 2 years following the interventions
- Observation had valid (not missing or unreasonable) LAZ values.

Observations that had null values for LAZ measurements were dropped form the analysis under the assumption that they were missing at random.

In the original data, latrine ownership was marked with a binary indicator (0 = no latrine, 1 = improved latrine). In the Bangladesh trials, data also indicated whether a household had an unimproved or improved latrine. Latrine indicators were refactored to categorical values with the levels “No latrine,” “Latrine no water seal,” and “Latrine with water seal” for Bangladesh and levels “No improved latrine” and “Improved latrine” for Kenya. Observations that had null values for latrine status were dropped form the analysis under the assumption that they were missing at random. In the Bangladesh dataset, observations that were marked as having a latrine but had null values for improved latrine status were assumed to have a latrine that did not have a function water seal (unimproved).

Calculation of differences

To find the unadjusted difference in mean LAZ between children in households without latrines at baselines and those in households in either improved or unimproved latrines, a generalized linear model with a gaussian family was fitted. Latrine status was set as the treatment and LAZ was set as the outcome. In the Bangladesh trials, two unadjusted models were created - one to compare households without latrines to households with unimproved latrines and one to compare households without latrines to households with improved latrines. Since the Kenya trials did not identify unimproved latrines, only one model needed to be created to compare households with improved latrines and households without improved latrines.

To find the adjusted difference in LAZ values, two methods were used:

- Generalized linear model with a gaussian family using latrine status as the treatment and LAZ as the outcome. Adjusted for covariates based on maximum likelihood ratios. This method drops observations with any missing values.
- Double robust targeted maximum likelihood estimation with a gaussian family using latrine status as the treatment and LAZ as the outcome. Adjusted for covariates based on maximum likelihood ratios. This method adjusts for missing values by substituting them with population means.
    - TMLE trains a combined model using simple mean, main terms GLM, main terms Bayes GLM, generalized additive models, and lasso models (glmnet)

Baseline covariates were defined in the analysis plan for the original WASH benefits study. They included child age, child sex, household food insecurity, birth order, maternal age, maternal education, maternal education, maternal height, number of children, distance to a water source, and various household characteristics and assets.

Results

To streamline the analysis process, the enrollment, treatment assignment, and anthropometry datasets were joined into a single data table by block, cluster, treatment, and child identifiers. After the data was merged, there were 10,046 rows in the Bangladesh dataset and 8,928 rows in the Kenya dataset.

In the merged dataset for Bangladesh, there were no observations with missing latrine status and 769 observations with unreasonable or missing LAZ measurements. In the merged dataset for Kenya, there were 150 observations with missing latrine status and 21 observations with unreasonable/missing LAZ measurements. After filtering for valid, end-line observations in the control/passive control group, there were 1,103 rows left in the Bangladesh dataset and 2,101 rows left in the Kenya dataset.

To visualize differences in LAZ measurements between the different groups, density plots were generated to show the distributions of LAZ values for each of the sanitation levels at enrollment (Figure 1). The LAZ distributions in each respective country appear to be relatively normal with similar means. From a glance, it appears that there is no significant difference in LAZ values between the groups of varying sanitation levels at enrollment.

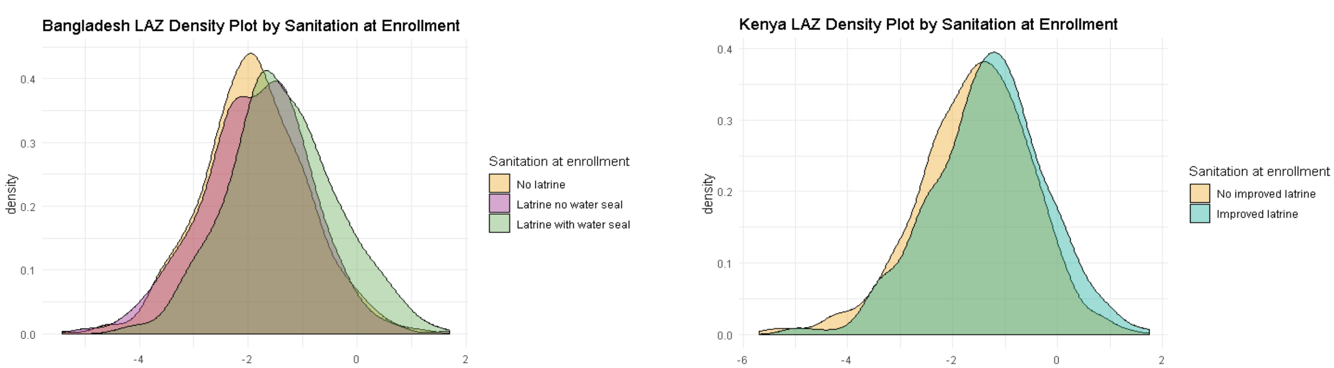

Figure 1. Density curves showing the comparative distributions of LAZ values between different levels of sanitation at enrollment. Bangladesh has three levels of sanitation (no latrine, latrine with no water seal, latrine with water seal) and Kenya has two levels (no improved latrine and improved latrine)

Mean LAZ Scores

Despite low levels of open defecation and access to improved latrines in the selected control villages in Kenya and Bangladesh, mean LAZ values were still low. Households in Bangladesh that possessed latrines with a water seal had a mean LAZ of -1.3739 and households in Kenya that possessed latrines with a slab had a mean LAZ of -1.3301.

This counteracts the claim that the WASH Benefits study may have observed higher increases in LAZ if trials had been completed in villages with less access to improved sanitation. This analysis shows that exposures outside the scope of the study are important determinants to growth faltering.

Differences in Mean LAZ Scores

Children in households with improved sanitation have higher mean LAZ measurements, even when adjusted for covariates. At the $\alpha = 0.05$ level, both countries saw a statistically significant difference in LAZ values between households with and without improved latrines. Improved latrines were associated with a LAZ increase of 0.2132 ($p = 0.0399$) in Bangladesh and a LAZ increase of 0.1461 ($p = 0.0361$) in Kenya when adjusted by a double-robust targeted maximum likelihood estimator.

It is important to note that the original WASH Benefits analysis did not include this comparison. The increase in LAZ measurements between the groups of different sanitation levels at enrollment suggests that preexisting improved latrines are a significant covariate that should be taken into consideration during future analysis. With this cofounding effect in mind, readers of the original WASH Benefits study should be careful in interpreting results relating sanitation interventions.

	Population (%)	Mean LAZ (SD)	Difference (95% CI)	P-value	Adjusted Difference - GLM (95% CI)	P-value	Adjusted Difference - TMLE (95% CI)	P-value
Bangladesh Control Groups								
No latrine	513 (47%)	-1.8939 (0.98)	Ref	Ref	Ref	Ref	Ref	Ref
Latrine with no water seal	391 (35%)	-1.8557 (1.00)	0.0382 (-0.08, 0.16)	0.5398	-0.0312 (-0.15, 0.09)	0.6159	-0.0289 (-0.17, 0.12)	0.6814
Latrine with water seal	199 (18%)	-1.3739 (1.01)	0.5200 (0.34, 0.69)	<0.0001	0.2002 (-0.06, 0.41)	0.0610	0.2132 (0.01, 0.42)	0.0399
Kenya Control Groups								
No improved latrine	1737 (83%)	-1.578 (1.08)	Ref	Ref	Ref	Ref	Ref	Ref
Improved latrine	364 (17%)	-1.3301 (1.08)	0.2479 (0.12, 0.37)	<0.0001	0.1619 (0.05, 0.28)	0.0064	0.1461 (0.01, 0.29)	0.0361

Figure 2. Results table. Contains population distribution of sanitation status at enrollment and unadjusted and adjusted differences in LAZ using "no latrine" measurements as reference values. Two methods were used to adjust differences for covariates: a gaussian generalized linear model and a double-robust targeted most likelihood estimator.

Conclusion

Following this secondary analysis WASH Benefits data, there is further evidence that traditional sanitation interventions do not drastically improve health outcomes. Children born into households that have improved sanitation still experience extensive growth faltering under WHO child growth standards. This analysis acknowledges that improved latrines offer a significant improvement in LAZ over no latrines, but children in households with latrines still face poor growth outcomes. These children continue to be exposed to human and animal fecal matter at home, resulting in the transmission of diarrheal disease. To address childhood growth faltering in rural areas, researchers should invest in the development of more comprehensive sanitation interventions such as sealing dirt floors or automatically chlorinating water sources. This data analysis also suggests that there are other important determinants of linear child growth beyond exposure to open defecation. Future research needs to take these factors into consideration in order to effectively address growth faltering in rural areas.

The sixth UN Sustainable Development Goal (SDG) upholds the need to "ensure access to water and sanitation for all" as a means of improving food security, economic opportunity, and overall quality of life.[1] There has been a large push in the global development community to develop effective, affordable WASH interventions to reduce the burden of diarrheal disease. While improvements in sanitation may not be strongly linked to childhood growth, there are known benefits to increased latrine access and reduced open defecation. Efforts to reduce diarrheal disease should continue to be pushed, but researchers must develop innovative solutions to address childhood growth faltering in the developing world.

References

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