Original Article

The role of water and sanitation, diarrheal infection, and breastfeeding on child stunting: insights from a historical analysis of the Cebu longitudinal health and nutrition survey, 1984–1986

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

ABSTRACT

Background: The association between improved water and sanitation (WATSAN) and child nutritional status may operate through diverse pathways and interact with other risk factors. We examined the joint association between WATSAN and child stunting in the Philippines during a historically critical period marked with substantial heterogeneity in WATSAN conditions.

Methods: Data came from the Cebu Longitudinal Health and Nutrition Survey. Birth surveys and bi-monthly follow-up surveys from 1984–1986 were used for the final analytic sample of 2,584 children. We ran a series of logistic regression models for WATSAN and child stunting at age 2, before and after adjusting for *a priori* selected covariates. We performed stratified analysis by the child's experience of diarrhea in the first 2 years (never vs. at least 1 incidence), and tested for interaction with breastfeeding practices in the first 6 months (never vs. partial vs. predominant).

Results: 53.9% of our sample were stunted at age of 2 and only 26.8% had access to improved WATSAN. In our final multivariate adjusted model, improved WATSAN was associated with a significantly reduced odds of stunting (odds ratio [OR], 0.59; $P < 0.01$). This was consistently found among children who have never experienced diarrheal incidence (OR, 0.38; $P = 0.03$) as well as those who have experienced diarrhea at least once (OR, 0.62; $P < 0.05$). A marginally significant interaction was found between WATSAN and breastfeeding ($P = 0.10$).

Conclusion: Ensuring access to improved WATSAN has great potentials to reduce child stunting, and this could occur through diverse pathways that do not necessarily involve clinically detectable signs of infection. Improved WATSAN appears to be relatively more important for children who are not breastfed. Future studies should explore these associations using more recent data and in the context of other low- and middle-income countries.

Keywords: Water; Sanitation; Stunting; Philippines; Diarrhea; Breastfeeding

Author Contributions

Conceptualization: Kim R, Fawzi WW;
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INTRODUCTION

Growth faltering and developmental impairment in early childhood are important public health challenges in low- and middle-income countries.^{1,2} Stunting, an anthropometric measure used to identify a deficit in height relative to age, signifies accumulated consequences of slowed skeletal growth often associated with long-term dietary inadequacy and repeated infections.³ The prevalence of stunting gradually increases from birth to 2 years of age and tends to level off after this critical period.⁴ Though a few studies have suggested the possibility of reversal in stunting up to age of 5 (i.e., catch-up in growth),^{5,7} in reality most stunted children who live in deprived environments fail to achieve their full growth potential.⁸ This is consequential because stunting is associated with poor cognitive and motor development as well as worse health outcomes.^{9,10} Further, linear growth faltering has inter-generational health effects as girls who were stunted at childhood have increased risk of mortality during childbirth and poorer pregnancy outcomes.¹¹

Epidemiological studies on determinants of anthropometric failures have consistently shown that household socioeconomic and environmental factors are the strongest predictors of child stunting.^{12,13} In particular, access to clean water, sanitation, and hygiene (WASH) is considered an important fundamental cause of child mortality and poor nutritional outcomes.^{5,14,15} Around 2.5 billion people worldwide still lack access to improved sanitation and 783 million people do not have access to improved drinking water sources.² It is estimated that 6.6% of the global burden of disease and disability is attributable to poor WASH conditions, with about 2.4 million deaths occurring annually due to diarrhea, subsequent malnutrition and their consequences.¹⁶ The association between WASH and child stunting may operationalize through direct pathways, including reduced risk of diarrhea, nematode infections and environmental enteropathy, as well as indirect pathways related to the family's ability to provide safe and clean living environments and having time to provide adequate care to their children.¹⁷

There are important gaps in the literature concerning WASH and child growth failures. Evidence on the benefit of WASH interventions on child nutritional status remains somewhat inconclusive,¹⁸ with a null effect on height-for-age z-score (HAZ) found in 3 non-randomized studies¹⁹⁻²¹ and an increase in HAZ detected in Ethiopia.²² Further, while diarrhea is conceptualized as an important mediator involved in the direct pathway between WASH and child growth, the *Lancet Maternal and Child Nutrition Series* estimated that hygiene and sanitation interventions implemented with 99% coverage would reduce diarrhea incidence by 30% but the prevalence of stunting by only 2.4% at 36 months of age.²³ Lastly, the role of WASH needs to be explored in relation to other known risk factors of child stunting given the increasing emphasis on integrating nutrition-sensitive programmes with nutrition-specific interventions.^{12,13} For instance, current public health guidelines strongly support for exclusive breastfeeding in the first 6 months as it can protect infants from exposure to water- and foodborne pathogens and also improve their resistance to infection.²⁴ Exclusive breastfeeding and improved WASH together may form a set of sequential barriers for protection. While interaction between WASH and breastfeeding has been explored in respect to diverse child health outcomes,²⁵⁻²⁸ evidence for child stunting is largely lacking.

Useful insights can be gained from a deeper look into a historically important period of economic development, urbanization, and demographic and health transitions. The 1980s and 1990s in the Philippines mark the beginning of a slow but important decline in child stunting, after which the progress has stagnated,²⁹ as well as substantial expansion in public

and private water infrastructures.³⁰ The development of water infrastructure, however, was not accompanied by adequate sanitation infrastructures, resulting in a context of heterogeneous conditions of water and sanitation (WATSAN) across the country.³¹ Hence, a historically informed assessment of this period can potentially inform current policies and interventions that aim to improve child health and development in other low- and middle-income countries.

The primary objective of this study was to investigate the joint association between WATSAN on stunting among children less than 2 years of age in Metro Cebu, Philippines. We constructed a joint categorical indicator with 4 levels of presumed quality of WATSAN by refining the international definition to the context of Metro Cebu in the 1980s. Second, we performed stratified analysis by the child's experience of diarrheal diseases in the first 2 years of life to assess the extent to which the association between WATSAN and stunting may operate through diverse pathways that do not necessarily involve diarrheal diseases. Lastly, we explored potential effect modification by breastfeeding practice during the first 6 months of life to examine whether the relationship between WATSAN and stunting varies according to the child's breastfeeding status.

METHODS

Data source

The Cebu Longitudinal Health and Nutrition Survey (CLHNS), part of an ongoing cohort study of Filipino women, was used for this study. The baseline survey started in 1983 with 33 barangays (17 urban, 16 rural) randomly selected from the Metro Cebu area using a single stage cluster sampling procedure.³² All pregnant women residing in the selected barangays and those who live elsewhere but delivered births in the selected barangay or any health facility located in the Metro Cebu area between 1 May, 1983 and 30 April, 1984 were eligible to join the study. Of the 3,711 women identified as eligible, a baseline interview was conducted among 3,327 women during the 6th to 7th month of their pregnancy so that all births could be identified.³² Detailed individual and household data on demographic and socioeconomic status (SES) were collected during the baseline interview. A birth information survey took place immediately after birth, with approximately 75% of all the interviews completed on or before the fifth day of the infants' births and 84.6% during the first week of life.^{32,33} During the first 2 years since birth of the child, bimonthly surveys—in the form of home visits—took place to collect dietary, morbidity, anthropometry, infant care, family planning, and related data. A detailed description of this stage of the field work was summarized in a prior study on the CLHNS project³² and is also available on their website: <http://www.cpc.unc.edu/projects/cebu>.

Study population

Of 3,327 women identified in the baseline interview, 743 were excluded due to their children dying before age of 2 or missing data on the main predictor (i.e., household WATSAN status) and/or the outcome (i.e., stunting). Children excluded due to missing data on the predictor and/or the outcome were compared to our final analytic sample of 2,584 children to assess whether the 2 groups significantly differ in terms of baseline characteristics.

Outcome

The main outcome of interest was child stunting at age of 2. In the CLHNS, the trained interviewers objectively measured anthropometric measurements of the infants during home visits at birth and every 2 months for the first 2 years. The interviewers used regularly

calibrated equipment, standard measurement techniques, and periodic checks for inter-observer reliability.³² Height measurements at 24 months were converted into HAZ following the National Center for Health Statistics/World Health Organization (WHO).³⁴ A child was categorized as stunted if his or her HAZ was 2 standard deviations below the reference median. If a child's height at 24th month was not available, we retrieved information from 22nd, 20th, and 18th month measurement, whichever was available first.

The WATSAN

The main predictor of interest was household's primary source of drinking water and type of toilet facility in use at the time of the baseline examination. Adhering closely to the WHO/the United Nations Children's Fund definition of improved versus unimproved WATSAN, as well as taking into account of our literature search on the context of Metro Cebu in the 1980s,^{30,35,36} we constructed a joint categorical variable 'WATSAN' with 4-levels of presumed quality: 1) Unimproved water and unimproved sanitation including public pipe/pump (in the absence of Metro Cebu Water District [MCWD] coverage), open well, spring, river, lake, rainwater and other unspecified water sources, and public latrine, Antipolo, open pit, none and other types of toilet; 2) Unimproved water but improved sanitation including private flush and water sealed toilets; 3) Improved water but unimproved sanitation including private pipe/pump, public pipe/pump (in the presence of MCWD coverage only) and purchased water sources; and 4) Improved water and improved sanitation. We formally tested for the interaction between WATSAN, but regardless of the result from this interaction test we used the 4-level joint indicator of WATSAN as the primary predictor variable for all analysis. For this categorical predictor, we treated the worst condition (i.e., unimproved water and unimproved sanitation) as the reference group for comparisons since it has the greatest clinical interpretability.

Diarrheal incidences

Each of the bimonthly follow-up surveys asked whether the infant had diarrhea during the past 7 days and whether the infant had diarrhea during the past 24 hours. For simplicity, if the mother responded 'no' to these 2 questions for all 12 follow-up questionnaires, the child was identified as never having experienced diarrheal incidences in the first 2 years of life. If the mother reported 'yes' at least once, then the child was identified as having experienced diarrhea in the first 2 years of life.

Breastfeeding

The birth survey and each of the bimonthly follow-up surveys also asked whether breast milk was fed to the infant 7 days ago and whether breast milk was fed to the infant the day before. If the mother responded 'yes' to these 2 questions for the first 4 questionnaires (including birth survey and follow-up surveys at 2, 4, and 6 months), the infant was categorized as having been predominantly breastfed for the first 6 months since birth. If the mother responded 'no' to these 2 questions for all 4 questionnaires, the infant was identified as never breastfed. If the mother responded 'yes' at least once and 'no' to others, or vice versa, the infant was categorized as partially breastfed.

Other covariates

Measures of household SES and child/maternal characteristics, identified as important predictors of child stunting in prior studies,^{12,13,37} were selected for adjustment in our analysis. SES factors, for instance, operate indirectly to affect children's nutritional status by determining the quality of the child's diet, care, and physical environment. As a proxy measure of the household's SES, we included residential area of the child's family (urban vs.

rural), household's ownership of television and radio (no vs. yes), type of cooking fuel the household uses (wood vs. electricity, kerosene, LPG, charcoal, and others), type of material the house is constructed from (light vs. mixed or strong), father's education (< 8 years vs. ≥ 8 years, indicating partial completion of secondary education), mother's education (< 8 years vs. ≥ 8 years), and whether the number of persons presently living in the household was greater than the national average household size (≤ 5 members vs. > 5 members). In addition, we included sex of the child (male vs. female), birth weight (≥ 2,500 g vs. < 2,500 g), mother's height, mother's age, whether it's the mother's first pregnancy (no vs. yes), and birth interval (≥ 2 years vs. < 2 years). Information on birth weight was either obtained from the hospital records or taken by midwives and manabangs who had helped birth delivery. We also adjusted for the total number of prenatal visits the mother had with private doctors, private nurses, government doctors, and midwives during pregnancy (< 4 visits vs. ≥ 4 visits). In order to retain consistent and maximum possible sample size, we dummy-coded missing values for binary and categorical covariates with incomplete data and replaced missing values with observed median for continuous covariates with incomplete data.

Statistical analysis

First, basic demographic and socioeconomic characteristics of our final analytic sample were compared by the levels of household WATSAN by generating frequency distributions for categorical variables and means with standard deviations for continuous variables. Then, a univariate logistic regression was performed to estimate the crude association between each covariate and child stunting. For the main analysis, we used multivariate logistic regression to model the log odds of a child being stunted with WATSAN as the primary 4-level predictor of interest and adjusting for all the aforementioned variables (X'): $\text{logit}(\pi) = \beta + \beta\text{WATSAN}_1 + \beta\text{WATSAN}_2 + \beta\text{WATSAN}_3 + \beta X'$. We diagnosed collinearity problem for each of the covariates by comparing the standard error of each effect estimates in the univariate analyses versus the corresponding standard error in multiple adjusted logistic regression model. Yet, because the covariates diagnosed as collinear may as well be confounders, we prioritized the inclusion of all covariates in our main effects model. Next, we performed a stratified analysis by running our multivariate adjusted logistic regression model separately among children who have never experienced diarrhea versus those who have experienced at least 1 incidence during first 2 years of life. Finally, we assessed the interaction between WATSAN and breastfeeding practices in respect to child stunting, and further preformed subgroup analysis by breastfeeding practices to estimate the association between WATSAN and stunting among children who were never, partially and exclusively breastfed in the first 6 months.

All data preparation and statistical analyses were performed using SAS 9.3. software (SAS Institute, Cary, NC, USA). We used the maximum likelihood estimation for the odds ratio (OR) estimates and the Wald χ^2 test for the P -values. For the primary predictor of WATSAN, we presented P -values for each level of WATSAN as well as an overall P -value (i.e., global type III) in respect to the outcome. The overall significance of multiplicative interaction term on the OR scale was determined by the P -value from the combined likelihood ratio test. All analyses were based on 2-tailed α set at $P \leq 0.05$ for statistical significance, unless specified otherwise.

RESULTS

A total of 836 children (32.4% of the total sample) were living in households with unimproved WATSAN, whereas 692 children (26.8% of the total sample) had access to improved WATSAN

Fig. 1. Prevalence of stunting among 2 year old children living in different conditions of WATSAN (n = 2,584). WATSAN = 0: unimproved water, unimproved sanitation; WATSAN = 1: unimproved water, improved sanitation; WATSAN = 2: improved water, unimproved sanitation; WATSAN = 3: improved water, improved sanitation. WATSAN = water and sanitation.

(Fig. 1). Of the total sample, the proportion of children living in households with improved water only (n = 794, 30.7%) was about 3-folds higher than those living in households with improved sanitation only (n = 262, 10.1%). Overall, more than half of our analytic sample (n = 1,393, 53.9%) were stunted at age of 2. The prevalence of stunting ranged from 37.7% for children in households with improved WATSAN to 64.0% for children in households with the worst WATSAN conditions (Fig. 1).

Table 1 summarizes the baseline characteristics of 2,584 children by WATSAN levels. Children from households with improved WATSAN were less likely to be born of low birth weight (5.6%) and were more likely to be the first child of the mother (25.0%). A majority of the children from households with improved water, regardless of sanitation status, were living in urban areas (> 97%). Improved water and/or improved sanitation was associated with higher SES. For instance, both parents of the households with improved WATSAN were more likely to have attended school for at least 8 years (~70%). Mothers from households with improved WATSAN were more likely to have attended more than 4 prenatal visits (16.6%). This trend reversed for breastfeeding behavior. It was more likely for the mothers in households with improved WATSAN to have never breastfed their children in the first 6 months of life (17.1%) while more than half of the mothers in households with unimproved WATSAN reported to have predominantly breastfed their child in the first 6 months since birth (55.3%) (Table 1). Among all the covariates, low birth weight, birth interval, maternal age and height, residency area, parental education, and household assets were found to be significantly associated with odds of stunting, even after controlling for all others (Table 2).

Main findings: WATSAN and stunting

In our main analysis, the results from both the univariate and multivariate logistic regression analyses indicated that the joint indicator of WATSAN was significantly associated with child stunting at age of 2 (global type III analysis $P < 0.01$) (Table 2). In the multivariate adjusted model, improved WATSAN was associated with 41% reduction in the odds of stunting compared to the reference group of unimproved WATSAN (OR, 0.59; $P < 0.01$) whereas

Table 1. Descriptive characteristic of 2,584 children from the Cebu Longitudinal Health and Nutrition Survey by WATSAN levels

Characteristics	Unimproved water, unimproved sanitation (WATSAN = 0, n = 836)	Unimproved water, improved sanitation (WATSAN = 1, n = 262)	Improved water, unimproved sanitation (WATSAN = 2, n = 794)	Improved water, improved sanitation (WATSAN = 3, n = 692)
Child/maternal characteristics				
Child's sex (female)	405 (32.4)	135 (51.5)	385 (48.5)	302 (43.6)
Low birth weight (< 2,500 g)	93 (11.1)	32 (12.2)	81 (10.2)	39 (5.6)
First pregnancy (yes)	135 (16.2)	53 (20.2)	162 (20.4)	173 (25.0)
Birth interval (< 2 yr)	119 (14.2)	40 (15.3)	142 (17.9)	119 (17.2)
Maternal age	26.5 ± 6.4	26.5 ± 5.8	25.5 ± 5.9	26.1 ± 5.5
Maternal height	150.3 ± 5.0	151.7 ± 5.1	150.2 ± 5.2	151.2 ± 5.0
Household socioeconomic status				
Residency area (urban)	325 (38.9)	159 (60.7)	772 (97.2)	681 (98.4)
Education level				
Father's education ≥ 8 yr	182 (21.8)	139 (53.1)	364 (45.8)	490 (70.8)
Mother's education ≥ 8 yr	181 (21.7)	134 (51.2)	347 (43.7)	480 (69.4)
Household characteristics				
TV ownership	32 (3.8)	63 (24.1)	96 (12.1)	284 (41.0)
Radio ownership	494 (59.1)	147 (56.1)	419 (52.8)	408 (59.0)
Modern cooking fuel	38 (4.6)	34 (13.0)	145 (18.3)	278 (40.2)
Strong construction material	357 (42.7)	181 (69.1)	396 (49.9)	544 (78.6)
> 5 people living	347 (41.5)	116 (44.3)	334 (42.1)	319 (46.1)
Child caring variables				
Prenatal care (≥ 4 visit)	41 (4.9)	24 (10.1)	68 (8.6)	115 (16.6)
Breastfeeding for first 6 mon				
Never breastfed	29 (3.5)	28 (10.7)	68 (8.6)	118 (17.1)
Partially breastfed	345 (41.3)	147 (56.1)	449 (56.6)	419 (60.6)
Predominantly breastfed	462 (55.3)	87 (33.2)	277 (34.9)	155 (22.4)

Data are shown as mean ± standard deviation or number (%).

WATSAN = water and sanitation.

improved sanitation alone (OR, 0.77; $P = 0.10$) and improved water alone (OR, 0.85; $P = 0.25$) were no longer significant after adjusting for all the covariates. The results remained consistent after excluding low birth weight, which may be a potential mediator in the association between WATSAN and child stunting (data not shown). In the first sensitivity analysis assessing the interaction between WATSAN in relation to stunting, we found no significant synergistic effect in both the unadjusted ($P = 0.17$) and the adjusted model ($P = 0.58$) (**Supplementary Table 1**).

Stratified analysis by diarrhea incidences

Based on available information from the bimonthly follow-up interviews for the first 2 years since birth, a majority of the children ($n = 2,152$, 83.3%) were reported to have experienced diarrhea at least once. Among children who had no reported diarrhea history based on the survey questionnaires, improved WATSAN was still significantly associated with lower odds of stunting (OR, 0.38; $P = 0.03$) (**Fig. 2**). In this group, improved sanitation only (OR, 0.47; $P = 0.15$) and improved water only (OR, 0.51; $P = 0.10$) was not significantly associated with stunting, but the associated ORs remained large and in consistent direction. Similarly, improved WATSAN was associated with 38% lower odds of stunting (OR, 0.62; $P < 0.01$) among children who had experienced diarrhea at least once.

Interaction by breastfeeding status

Based on the bimonthly follow-up interviews for the first 6 months since birth, 243 children (9.4%) were found to have been never breastfed, 1,360 (52.6%) were identified as partially breastfed, and 981 (38.0%) were classified as predominantly breastfed. After adjusting for all covariates, the interaction between WATSAN and breastfeeding in respect to child stunting was only marginally significant ($P = 0.10$) (**Table 3**). Improved WATSAN was associated with

Table 2. Unadjusted and adjusted associations between WATSAN levels, selected covariates, and child stunting (n = 2,584)

Characteristics	Univariate		Multivariate adjusted ^a	
	OR (95% CI)	P-value	OR (95% CI)	P-value
WATSAN				
Unimproved water, unimproved sanitation (WATSAN = 0)	1	-	1	-
Unimproved water, improved sanitation (WATSAN = 1)	0.54 (0.41–0.71)	< 0.01	0.77 (0.56–1.06)	0.10
Improved water, unimproved sanitation (WATSAN = 2)	0.81 (0.67–0.99)	0.04	0.85 (0.66–1.12)	0.25
Improved water, improved sanitation (WATSAN = 3)	0.34 (0.28–0.42)	< 0.01	0.59 (0.44–0.79)	< 0.01
Global (type III analysis)		< 0.01		< 0.01
Child/maternal characteristics				
Child's sex (female)	0.97 (0.83–1.14)	0.72	0.88 (0.74–1.05)	0.15
Low birth weight (< 2,500 g)	3.18 (2.33–4.33)	< 0.01	2.53 (1.81–3.54)	< 0.01
First pregnancy (yes)	0.60 (0.50–0.73)	< 0.01	0.97 (0.53–1.77)	0.93
Birth interval (< 2 yr)	1.34 (1.07–1.67)	0.01	1.37 (1.07–1.75)	0.01
Maternal characteristics				
Maternal age	1.00 (0.99–1.01)	0.85	0.98 (0.97–1.00)	0.05
Maternal height	0.89 (0.88–0.91)	< 0.01	0.91 (0.89–0.92)	< 0.01
Household socioeconomic status				
Residency area (urban)	0.75 (0.63–0.90)	< 0.01	1.38 (1.06–1.79)	0.02
Education level				
Father's education ≥ 8 yr	0.41 (0.35–0.48)	< 0.01	0.71 (0.58–0.87)	< 0.01
Mother's education ≥ 8 yr	0.41 (0.35–0.48)	< 0.01	0.74 (0.61–0.91)	< 0.01
Household characteristics				
TV ownership	0.32 (0.26–0.40)	< 0.01	0.57 (0.44–0.74)	< 0.01
Radio ownership	0.88 (0.76–1.03)	0.12	0.86 (0.72–1.02)	0.08
Modern cooking fuel type	0.39 (0.32–0.48)	< 0.01	0.65 (0.51–0.83)	< 0.01
Strong construction material	0.55 (0.47–0.64)	< 0.01	0.92 (0.76–1.11)	0.39
> 5 people living	1.18 (1.01–1.37)	0.04	1.40 (1.16–1.69)	< 0.01
Child caring variables				
Prenatal care (≥ 4 visit)	0.52 (0.39–0.68)	< 0.01	0.86 (0.63–1.18)	0.38
Breastfeeding for first 6 mon				
Partial vs. never breastfed	1.67 (1.26–2.20)	< 0.01	1.02 (0.74–1.41)	0.90
Predominant vs. never breastfed	2.29 (1.72–3.05)	< 0.01	1.07 (0.76–1.51)	0.70

WATSAN = water and sanitation; OR = odds ratio; CI = confidence interval.

^aAdjusted for residential area of the child's family (urban vs. rural), household's ownership of television and radio (no vs. yes), type of cooking fuel the household uses (wood vs. electricity, kerosene, LPG, charcoal, and others), type of material the house is constructed from (light vs. mixed or strong), father's education (< 8 years vs. ≥ 8 years), mother's education (< 8 years vs. ≥ 8 years), number of persons presently living in household (≤ 5 members vs. > 5 members), sex of the child (male vs. female), low birth weight (≥ 2,500 g vs. < 2,500 g), mother's height, mother's age, whether it's the women's first pregnancy (no vs. yes), previous birth interval (≥ 2 years vs. < 2 years), prenatal visits the child's mother had during pregnancy (< 4 visits vs. ≥ 4 visits), and breastfeeding practice at 6 months (never, partial, and predominant).

significant reduction in the odds of stunting among never breastfed (OR, 0.27; $P = 0.02$) and predominantly breastfed children (OR, 0.52; $P = 0.01$), but only marginally for partially breastfed children (OR, 0.70; $P = 0.07$). Living in households with access to improved sanitation only, compared to living in households with unimproved WATSAN, was still associated with 79% reduction in the odds of stunting ($P = 0.05$) among children never breastfed. Access to improved water alone was significantly associated with reduction in the odds of stunting for predominantly breastfed children only (OR, 0.62; $P = 0.03$) (Table 3).

DISCUSSION

Our study using the CLHNS baseline survey on 2,584 Filipino children presents 3 salient findings. First, we found a statistically significant association between improved WATSAN and reduced odds of child stunting after adjusting for a comprehensive set of potential confounders. Second, the stratified analysis by experience of diarrhea showed that the protective association between WATSAN and stunting was equally significant for both

Table 3. Interaction test^a and stratified analysis to assess the association between WATSAN and child stunting by breastfeeding practices (n = 2,584)

Breastfeeding practices	Unadjusted						Multivariate adjusted ^b					
	Unimproved water, improved sanitation (WATSAN = 1)		Improved water, unimproved sanitation (WATSAN = 2)		Improved water, improved sanitation (WATSAN = 3)		Unimproved water, improved sanitation (WATSAN = 1)		Improved water, unimproved sanitation (WATSAN = 2)		Improved water, improved sanitation (WATSAN = 3)	
	OR ^c (95% CI)	P	OR ^c (95% CI)	P	OR ^c (95% CI)	P	OR ^c (95% CI)	P	OR ^c (95% CI)	P	OR ^c (95% CI)	P
Never breastfed (n = 243)	0.14 (0.05–0.37)	< 0.01	0.44 (0.19–0.99)	0.05	0.12 (0.05–0.26)	< 0.01	0.21 (0.06–0.68)	0.05	0.43 (0.15–1.29)	0.24	0.27 (0.09–0.84)	0.02
Partially breastfed (n = 1,360)	0.55 (0.37–0.81)	< 0.01	0.90 (0.68–1.20)	0.48	0.39 (0.29–0.52)	< 0.01	0.77 (0.50–1.18)	0.23	1.03 (0.72–1.47)	0.88	0.70 (0.48–1.03)	0.07
Predominantly breastfed (n = 981)	0.74 (0.46–1.17)	0.20	0.82 (0.60–1.11)	0.19	0.49 (0.34–0.70)	< 0.01	0.89 (0.53–1.49)	0.65	0.62 (0.40–0.96)	0.03	0.52 (0.31–0.87)	0.01

WATSAN = water and sanitation; OR = odds ratio; CI = confidence interval.

^aInteraction test *P*-value = 0.02 in unadjusted model, *P* = 0.10 in multivariate adjusted model; ^bAdjusted for residential area of the child's family (urban vs. rural), household's ownership of television and radio (no vs. yes), type of cooking fuel the household uses (wood vs. electricity, kerosene, LPG, charcoal, and others), type of material the house is constructed from (light vs. mixed or strong), father's education (< 8 years vs. ≥ 8 years), mother's education (< 8 years vs. ≥ 8 years), number of persons presently living in household (≤ 5 members vs. > 5 members), sex of the child (male vs. female), low birth weight (≥ 2,500 g vs. < 2,500 g), mother's height, mother's age, whether it's the women's first pregnancy (no vs. yes), previous birth interval (≥ 2 years vs. < 2 years), prenatal visits the child's mother had during pregnancy (< 4 visits vs. ≥ 4 visits), and breastfeeding practice at 6 months (never, partial, and predominant); ^cThe reference group for all ORs is Unimproved Water, Unimproved Sanitation (WATSAN = 0).

groups, suggesting the importance of diverse pathways that may or may not involve diarrheal infection. Lastly, we found a marginally significant interaction between WATSAN and breastfeeding practice in respect to child stunting. The association between WATSAN and stunting was most significant among never breastfed children followed by predominantly breastfed children, and had marginally significant association for partially breastfed children.

Fig. 2. Stratified analysis to assess the association between (WATSAN and child stunting by experience of diarrhea in the first 2 years^a (n = 2,584). WATSAN = 0: unimproved water, unimproved sanitation; WATSAN = 1: unimproved water, improved sanitation; WATSAN = 2: improved water, unimproved sanitation; WATSAN = 3: improved water, improved sanitation.

WATSAN = water and sanitation; OR = odds ratio.

^aAdjusted for residential area of the child's family (urban vs. rural), household's ownership of television and radio (no vs. yes), type of cooking fuel the household uses (wood vs. electricity, kerosene, LPG, charcoal, and others), type of material the house is constructed from (light vs. mixed or strong), father's education (< 8 years vs. ≥ 8 years), mother's education (< 8 years vs. ≥ 8 years), number of persons presently living in household (≤ 5 members vs. > 5 members), sex of the child (male vs. female), low birth weight (≥ 2,500 g vs. < 2,500 g), mother's height, mother's age, whether it's the women's first pregnancy (no vs. yes), previous birth interval (≥ 2 years vs. < 2 years), prenatal visits the child's mother had during pregnancy (< 4 visits vs. ≥ 4 visits), and breastfeeding practice at 6 months (never, partial, and predominant).

There are few important limitations to note. First, we utilized the baseline and bimonthly follow-up surveys collected in 1984–1986. While this marks an important period of economic development and expansion of water service provision in Metro Cebu that merits value for our historical analysis, we urge cautious extrapolation of our findings. For instance, we do not intend to make inferential claims for the current population of the Philippines given the dramatic changes in living conditions over the past 3 decades. However, the policy implication of our findings from the assessment of the joint impact of WATSAN on child stunting are still relevant for low-income countries where child stunting remains high and quality of WATSAN continues to be poor. Moreover, while we focused on the baseline surveys given our interest in child stunting in the first 2 years of life, longitudinal analysis incorporating data from later waves can be done in future studies to assess the long-term health consequences of improved WATSAN. Second, the results from our stratified analysis by diarrheal incidence should be interpreted in light of the fact that because the bi-monthly surveys used recall period of up to 7 days for this question, diarrhea history that occur outside of this recall period may not have been captured. Therefore, the subgroup identified as never having experienced diarrhea incidence is purely based on available data and may include children with earlier diarrheal history.

Another potential limitation is concerned with the children who were excluded from our study due to missing data on the primary predictor and outcome. Although they did not differ from the children in our final analytic sample in terms of height at birth, maternal height, maternal age, TV ownership, fuel type used for cooking and the material the house was constructed from, they were substantially different in terms of baseline WATSAN status (χ^2 test $P < 0.01$), area of residence, radio ownership, parental education level, first pregnancy rate, and low birth weight. Finally, we do not claim causality from this observational analysis. Although we adjusted for a large set of SES and maternal/child characteristics in our logistic regression models to minimize confounding bias, there may be other unobserved household or child characteristics that are associated with both child stunting and WATSAN status. Moreover, covariates adjusted in our model may be a potential mediator between WATSAN and child stunting. However, our results remained consistent after excluding variables like low birth weight. More rigorous study designs should be employed to assess the causal association between WATSAN and child stunting.

Despite these limitations, the large sample size of the CLNHS cohort and the high prevalence of stunting gave adequate power for our models to detect small differences in associations and to evaluate interactions. When interpreted in light of prior literature, our study makes meaningful contributions to our understanding of the complex relationship between WATSAN and child growth. Prior observational studies found protective association of improved WATSAN on greater HAZ and lower risk of stunting across diverse countries, including Sudan,⁵ Peru,³⁸ Bangladesh,³⁹ Philippines,²⁷ and Lesotho.⁴⁰ Using nationally representative cross-sectional samples from 8 countries, Esrey⁴¹ estimated that an improvement in sanitation was associated with 0.06–0.65 increments in HAZ while improved water source was associated with smaller benefits to height that were only apparent when sanitation was also improved. A global study⁴² utilizing merged data across 70 low- and middle-income countries over the period of 1986–2007 found access to improved sanitation to significantly lower the risk of stunting. They also found significant but smaller effect estimate for access to improved water.⁴² Conditional on a comprehensive set of covariates, we also found similar associations in the context of Metro Cebu with the largest protective effect observed for children with access to both improved WATSAN.

Moreover, the implication of our findings from the subgroup analysis by experience of diarrhea supports literature on the environmental enteropathy hypothesis to some extent.⁴³ Environmental enteropathy is an energy-intensive subclinical condition, characterized by villous atrophy, crypt hyperplasia, increased permeability, inflammatory cell infiltrate and modest malabsorption.⁴⁴ These processes impair absorptive and barrier functions of the small intestine mucosa lining, and ultimately cause growth to falter. For instance, clinical or subclinical inflammation prevents iron absorption in the context of limited micronutrient-rich foods. The constant state of immune stimulation, even in the absence of overt clinical disease, could have cumulative effects with adverse developmental outcomes in the context of poverty.⁴⁵ Prior studies on growth failure in African children have demonstrated mechanisms linking chronic asymptomatic mucosal enteropathy to growth failure.^{46,47} In the context of our study in which 63.1% (n = 1,630) of the children lived in households with unimproved sanitation and 42.3% (n = 1,098) lived in households with unimproved water sources, it is highly plausible that their constant exposure to human and animal feces provided a low level of chronic immune stimulation with catabolic consequences that increased their risk of stunting, even if they did not exhibit clinically detectable signs of infection (i.e., diarrhea). Taken together, this suggests that interventions and programmes focused on reduction of clinical diarrhea as a measure to evaluate the health benefits of improved WATSAN may be inadequate.

Lastly, our results from the interaction test between WATSAN and breastfeeding is highly relevant for interventions that seek to promote breastfeeding practices among mothers in low-income settings. Having access to improved WATSAN was associated lower risk of child stunting for both never breastfed and predominantly breastfed children, but the magnitude of association was much stronger among children who were never breastfed in the first 6 months. That is, breastfeeding was found to be more important in the context of poor WATSAN where house environment is more likely to be contaminated with faecal material. Prior literature suggests that partially breastfed infants still benefit from maternal antibodies in breastmilk, albeit the magnitude of this protection would be much smaller than that from exclusive breastfeeding.⁴⁸⁻⁵⁰ We found the association between WATSAN and stunting to be weaker and only marginally significant among partially breastfed children. At the same time, a much stronger interactive effect between WATSAN and breastfeeding has been observed in respect to outcomes of infant mortality and diarrhea.^{28,48} These findings collectively suggest that programmes on breastfeeding promotion and education may consider prioritizing mothers living in communities with poorer WATSAN conditions.

Our historically informed analysis emphasizes the importance of structural changes to improve environmental conditions to reduce child stunting in low- and middle-income countries. While our findings should be interpreted in light of the presence of different context-specific risk factors that may vary over time, the need for access to higher quality WATSAN facilities to improve child health is universal. What remain to be better appreciated are the mechanisms underlying the beneficial role of WATSAN and its relation to other known risk factors of child growth and development. Our findings indicate that the harmful effects of poor WATSAN on child stunting may be mediated through pathways other than diarrheal incidences. For instance, poor gut health and chronic immune stimulation by exposure to contaminated environment may prevent absorption of micronutrients and therefore have cumulative effects with adverse developmental outcomes. The results from our interaction test between WATSAN and breastfeeding practices suggests that interventions promoting breastfeeding could perhaps prioritize mothers living in households with poor WATSAN

(especially those with poor sanitation). Future studies should explore these associations using more recent data and in the context of other low- and middle-income countries.

SUPPLEMENTARY MATERIAL

Supplementary Table 1

Interaction test between water and sanitation on child stunting

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