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Risk factors for early childhood growth faltering in rural Cambodia: a cross-sectional study

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ABSTRACT

Objective This study aimed to determine risk factors of growth faltering by assessing childhood nutrition and household water, sanitation, and hygiene (WASH) variables and their association with nutritional status of children under 24 months in rural Cambodia.

Design We conducted surveys in 491 villages (clusters) randomised across 55 rural communes in Cambodia in September 2016 to measure associations between child, household and community-level risk factors for stunting and length-for-age z-score (LAZ). We measured 4036 children under 24 months of age from 3877 households (491 clusters). We analysed associations between nutrition/WASH practices and child growth (LAZ, stunting) using generalised estimating equations (GEEs) to fit linear regression models with robust SEs in a pooled analysis and in age-stratified analyses; child-level and household-level variables were modelled separately from community-level variables.

Results After adjustment for potential confounding, we found household-level and community-level water, sanitation and hygiene factors to be associated with child growth among children under 24 months: presence of water and soap at a household's handwashing station was positively associated with child growth (adjusted mean difference in LAZ +0.10, 95% CI 0.03 to 0.16); household-level use of an improved drinking water source and adequate child stool disposal practices were protective against stunting (adjusted prevalence ratio (aPR) 0.80, 95% CI 0.67 to 0.97; aPR 0.82, 95% CI 0.64 to 1.03). In our age-stratified analysis, we found associations between child growth and community-level factors among children 1–6 months of age: shared sanitation was negatively associated with growth (−0.47 LAZ, 95% CI −0.90 to −0.05 compared with children in communities with no shared facilities); improved sanitation facilities were protective against stunting (aPR 0.43, 95% CI 0.21 to 0.88 compared with children in communities with no improved sanitation facilities); and open defecation was associated with more stunting (aPR 2.13, 95% CI 1.10 to 4.11 compared with children in communities with no open defecation). These sanitation risk factors were only measured in the youngest age strata (1–6 months). Presence of water and soap at the household level were associated with taller children in the 1–6 month and 6–12 month age strata (+0.10 LAZ, 95% CI −0.02 to 0.22 among children 1–6 months of age; +0.11 LAZ, 95% CI −0.02 to 0.25 among children 6–12 months of age compared with children in households with no water and soap). Household use of improved drinking water source was positively associated with growth among older children (+0.13 LAZ, 95% CI −0.01 to 0.28 among children 12–24 months of age).

Conclusion In rural Cambodia, water, sanitation and hygiene behaviours were associated with growth faltering among children under 24 months of age. Community-level sanitation factors were positively associated with growth, particularly for infants under 6 months of age. We should continue to make effort to: investigate the relationships between water, sanitation, hygiene and human health and expand WASH access for young children.

Strengths and limitations of this study

- To date, few studies have investigated associations between WASH factors and child health in rural Cambodia.
- As a cross-sectional study, we were unable to assess directionality of associations, or infer causality between measured variables.
- Village-scale estimates of coverage may or may not be reflective of a child's exposure to the environment.
- This study only captures exposures at one point in time, but longer term effects of these exposures may not be apparent until later in life.
- Younger children, particularly under 6 months of age, may receive particular attention and care and different child-feeding practices; the survey used for this study was not designed to delineate exclusive breastfeeding from general breastfeeding.

INTRODUCTION

Childhood growth faltering has been directly linked with adverse outcomes later in life, including poorer school achievement, diminished intellectual functioning, reduced earnings later in life and lower birth weight for infants born to women who are stunted.[1 2] Inadequate nutrition has been implicated as a key driver of poor growth outcomes. Interventions that aim to improve child linear growth are typically targeted for children between 6 and 24 months of age, which is the period critical for cognitive growth and after which is much more difficult to reverse the effects on stunting.[3] On measuring growth outcomes, there is evidence that growth failure at a very young age is strongly linked to shorter adult stature[4] and puts children at higher risk of death by 24 months of age.[5]

Since growth faltering in children is thought to be primarily attributable to inadequate nutrition, many studies have focused on improving infant and child nutrition[6–8] and maternal health[5] to achieve better growth. However, nutrition behaviours that aim to ensure adequate dietary intake alone have not been successful in eliminating stunting altogether,[6] suggesting the need for additional complementary behaviours that might act synergistically to accelerate progress in countering undernutrition.[9] Enteric infections in early childhood have been shown to impact child growth,[10] primarily via environmental enteric dysfunction.[11 12] Interventions to reduce pathogen exposure, including safe water, effective sanitation, and hygiene (WASH), may therefore play a role in supporting child growth outcomes. These interventions can be directed at both household and community level.

Southeast Asia has seen major reductions in childhood stunting in the last two decades.[13] The prevalence of stunting remains high in Cambodia, however. Cambodia Demographic and Health Survey (CDHS) data from 2014 reported as many as 33% (95% CI 32% to 34%) of children under 5 years are stunted and 9% (95% CI 8.7% to 10%) are severely stunted, defined as having a length-for-age z-score less than 2 and 3 SD from the WHO reference population[14]; rural populations in Cambodia experience poorer growth outcomes with 36% (95% CI 34% to 37%) of children under 5 years stunted and 11% (95% CI 9.5% to 12%) of children severely stunted.[15] Stunting has been found to be more prevalent among children in rural settings compared with children in urban settings,[16 17] although this association may be more strongly associated with poverty.[16]

The evidence base for sanitation improvements in rural households alone to improve child health is mixed.[7 8 18–20] Increasing sanitation coverage may provide 'herd protection'—by reaching a level of sanitation coverage that effectively contains waste to reduce overall exposure to enteric pathogens in a community—and could support improved growth outcomes in children.[21–24] A recent study in Cambodia found community-level open defecation to be associated with decreased length for age.[25] Another study of CDHS data (2000–2010) examined risk factors for poor growth outcomes and found a reduction of stunting attributable access to any household sanitation (flush facilities, pit latrines or composting toilets[26]). Because integrated nutrition and rural sanitation programming are widely being considered as interventions to reduce undernutrition in rural development initiatives,[7 8 20] this study aims to provide a broad examination of risk factors for undernutrition that focus on child feeding practices and specific household and community-scale WASH measures common in rural Cambodia. Several recent trials[7 8 18 19 27–30] have sought to measure effects of WASH interventions on growth outcomes in children under 2 years of age. We examined associations between concurrent WASH and nutritional variables and growth status in children under 24 months in rural Cambodia.

METHODS

Study and survey design

We measured associations between key WASH and nutrition practices on child linear growth in rural households and villages in three provinces of Cambodia. We conducted this cross-sectional study in 491 villages spanning 55 rural communes of Pursat, Siem Reap, and Battambang provinces in September 2016. Each survey was completed in approximately 30 min, and all surveys were completed within a 5-week period. We developed the survey questionnaire based on validated questions from CDHS[15]; survey question modules are summarised in table 1. Data collection and data quality assurance are detailed in online supplemental information.

Communes were eligible if two key criteria were met: at least 30% of the population lived below the poverty line according to the 2011 Cambodia Ministry of Planning's Commune Database; and latrine subsidies were not in place, which were both associated with potential short-term changes in sanitation coverage. Households were eligible if they had children under 24 months of age. Households were randomly selected from the eligible pool for inclusion in the survey using a random number generator (StataCorp LLC). Household selection is detailed in online supplemental information.

We estimated sample size to allow for hypothesis testing in a future randomised controlled study, with assignment to groups randomised at the commune (cluster) level. Using a baseline mean LAZ of −1.64 with a SD of 1.29 from the 2014 CDHS dataset,[15] we estimated this study had 80% power (beta) to detect a minimum detectable effect size of 0.18 in length-for-age z-score at 95% significance (alpha=0.05).[7 18 20] We used an intra-cluster coefficient of 0.01 using the Cambodia Helping Address Rural Vulnerabilities and Ecosystem Stability dataset. Complete sample size calculations are provided in the online supplemental information.

For child-level variables, 4036 children under 24 months of age from 3877 households (approximately eight households per village) were surveyed and had anthropometric measures taken. Two hundred and forty-four children were excluded from the adjusted analyses due to incomplete survey data. For some child-level nutrition variables specifically, 2724 children between 6 and 24 months of age had dietary diversity scores and meal frequencies measured. For village-level WASH variables, a total of 5341 households (approximately 11 households per village) were surveyed.

Table 1 Survey questionnaire modules

Modules	Indicators
I. Basic information from primary caregiver	▶ Age, religion, schooling and marital status. ▶ Spouse's schooling. ▶ Household size, number of adults and children.
II. Basic information for children (0–24 months)	▶ Gender, birthdate and birth weight (document verification). ▶ Breastfeeding.
III. Child anthropometry measurements (0–24 months)	▶ Weight. ▶ Height.
IV. Child health (diarrhoea and other illness) (0–24 months)	▶ Vomit and abdominal pain. ▶ Diarrhoea in last 7 days and in last 2 weeks. ▶ Duration and intensity of diarrhoeal episode.
V. Child dietary diversity (6–24 months)	▶ Dietary intake from the previous day. ▶ Meal frequency.
VI. Family size, pregnancy and child births.	▶ Antenatal care, currently pregnant. ▶ Total births and birth spacing. ▶ Child mortality.
VII. Exposure to nutrition and sanitation/hygiene interventions in last 12 months	▶ Receipt of different nutrition and sanitation/hygiene-related products. ▶ Participation in nutrition or sanitation village-level activities.
VIII. Household WASH conditions	▶ Drinking water source, access, and treatment. ▶ Handwashing station (observation). ▶ Sanitation facility (observation). ▶ Disposal of child's stool.
IX. Household characteristics	▶ Asset inventory. ▶ Fuel source. ▶ Floor, roof and wall material (observation). ▶ Number of rooms. ▶ IDPoor cardholder (document verification).

WASH, water, sanitation, hygiene.

Study variables

The two primary outcomes were length-for-age z-score (LAZ; continuous scale) and stunting (dichotomised, defined as LAZ less than −2 SD from the 2006 WHO International Reference Standard[14]) at the individual child level and at the village level, expressed as a mean value. Length measurement procedures were performed following Food and Nutrition Technical Assistance (FANTA) guidelines (online supplemental information). Recumbent lengths were taken per FANTA guidelines, which suggest a recumbent length measurement for children 0–24 months. All anthropometric measurement was performed in duplicate by trained enumerators, and if values differed by >1.0 cm, a third was taken or until successive measurements were <1.0 cm in difference. Final length and weight measurements for z-score calculations were made by taking the mean of the two measurements within the error threshold of 1.0 cm.[31]

The conceptual framework underpinning this analysis is derived from previous literature[10 25 26] and includes a range of nutrition, water, sanitation and hygiene variables that could plausibly influence child growth. Child-level nutrition variables included breastfeeding (dichotomous, based on whether child was breast fed yesterday), dietary diversity (dichotomous, based on whether the recommended minimum of four out of seven of food groups was consumed in the previous 24 hours), meal frequency (dichotomous, based on whether the recommended minimum was met) and minimum acceptable diet (dichotomous, based on whether minimum dietary diversity and minimum meal frequencies were met). The household-level water variable included access to an improved drinking water source (dichotomous). The household-level hygiene variable included availability of water and soap at a handwashing station (dichotomous). Sanitation variables were measured at the household and community level. Household sanitation variables included practice of open defecation (dichotomous), use of a shared sanitation facility (dichotomous), access to an improved sanitation facility (dichotomous) and proper disposal of child stool (dichotomous). Community-level sanitation variables were the same as household-level variables, calculated using village-level means with poststratification weights (described previously).

Statistical methods

We performed a stratified risk factor analysis using age strata of 1–6, 6–12 and 12–24 months of age to assess age-associated effects on outcomes, since children under 6 months of age may have higher maternal care and different child feeding practices and children under 12 months of age are less mobile and may experience different environmental exposures compared with older children in our cohort. Primary analysis to identify potential risk factors included modelling effects of child-level, household-level and community-level WASH variables on child-level undernutrition outcomes. For LAZ, we calculated bivariate and adjusted associations (as mean differences) with 95% CIs using generalised estimating equations (GEEs) to fit linear regression models with robust SEs.[32] For stunting, we calculated unadjusted and adjusted prevalence ratios (PRs) with 95% CIs using GEEs to fit Poisson regression models with robust standard errors.[33] All models assessing effects of household-level variables were adjusted for village-level clustering. Models assessing effects of community-level variables were separate from models assessing child-level and household-level variables to allow for comparisons of community-level variables independent of household practices. To test for presence of multicollinearity between covariates, we calculated variance inflation factors (VIFs). All covariates chosen had VIF <5, suggesting no detectable presence of multicollinearity.[34] Postestimation tests were employed to check for model fitness; models with goodness-of-fit χ^2 less than 0.10 were not included.

Covariates were considered as potential confounders using a 'common cause' approach[35] and on the basis of the conceptual framework describing proposed child feeding practices and WASH variables affecting child nutritional status.[10] In adjusted analyses, we included the following covariates, identified a priori: child sex (dichotomous), child age (continuous, in months), child birth weight (continuous, in kilograms), child illness (dichotomous, based on whether caregiver reported any diarrhoea, bloody stool, vomiting, fever or abdominal pain in the previous week), maternal age (continuous, in years), maternal education (dichotomous, based on whether mother attended primary school or higher), household size (continuous, number of household members) and household wealth index quintile (ordinal).

We performed a supplemental analysis to better understand the effects of community-level WASH variables using mixed effects regression to model the effects of community-level WASH on LAZ and prevalence stunting, with villages as a fixed effect. GEEs were not used because clustering may have attenuated community-level effects.

RESULTS

Table 2 summarises results from the primary survey that captures household, demographic and WASH characteristics of households with children under 2 years of age. Households had an average size of five members with two to three children from 2 to 18 years of age and one child below 2 years of age. Most households had a finished floor (95%) and mobile phone (86%), but only 50% had electricity. The mean maternal age was 29.4 year, and most mothers (84%) had attended primary school.

The average age of children measured was 11 months, with approximately 57% (2270/3988) younger than 12 months and 43% (1718/3988) between 12 and 24 months old. Slightly less than half (47.8%) of the children were girls, and the average birth weight was 3.1 kg. High prevalence of breastfeeding was observed among young children 0–12 months old (94% of children 0–12 months old and 53% of children 12–24 months old). The mean LAZ for all children was −0.96 (SD 1.16), with older children (12–24 months) having worse growth outcomes (LAZ −1.32, SD 1.16) than younger children (0–12 months, LAZ −0.69, SD 1.06). Similarly, older children (12–24 months) had higher stunting levels (24%, SD 30%) than younger children (0–12 months, 10%, SD 42%). Caregivers reported diarrhoea with a 7-day recall in 25% of children and with a 14-day recall in 7% of children.

Fifty-five per cent of all children consumed the recommended minimum frequency of meals,[36] while only of 36% of children over 6 months consumed the recommended minimum dietary diversity. Most households surveyed

Table 2 Child, household (HH), water, sanitation and hygiene characteristics of households with children <24 months of age

HH with children	N	% or mean	SD
Child characteristics			
Child age (months)	4064	11.1	6.6
Male	4082	52%	50%
Child birth weight (kg)	4033	3.07	0.46
Currently breastfed (all children)	3979	77%	42%
Currently breastfed (children 0–6 months)	1114	98%	15%
Currently breastfed (children 6–12 months)	1155	91%	28%
Currently breastfed (children 12–18 months)	943	72%	45%
Currently breastfed (children 18–24 months)	767	31%	46%
Solid foods introduced (children 6–8 months)	521	88%	32%
Ever breastfed	4082	98%	14%
Length-for-age z-score (LAZ)	3984	−0.96	1.16
Stunted	3984	16%	37%
Caregiver-reported diarrhoea (7-day recall)	4082	25%	43%
Caregiver-reported diarrhoea (14-day recall)	4082	7%	26%
Blood in stool (7-day recall)	4082	2%	13%
Vomit (7-day recall)	4082	8%	27%
Fever (7-day recall)	4082	20%	40%
Abdominal pain (7-day recall)	4082	18%	39%
Any illness	4082	42%	49%
Minimum dietary diversity met (children >6 months)	2957	36%	48%
Minimum meal frequency met	4082	55%	50%
Minimum acceptable diet met (children >6 months)	2957	37%	1%
Household characteristics			
Household size	4082	5.5	2.2
Number of children in HH (2–18 years)	4082	2.5	1.4
Number of children in HH (<24 months)	4082	1.1	0.3
Has electricity	4082	50%	50%
Owns a mobile phone	4082	85%	36%
Has a finished floor*	4081	95%	22%
Primary caregiver has attended primary school	4080	84%	36%
Maternal age (years)	4066	29.4	9.1
Improved drinking water source†	4072	85%	36%
Water source on site	4082	78%	41%
Water source is <5 min, roundtrip	893	13%	96%

Continued

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Table 2 Continued

HH with children	N	% or mean	SD
Minutes to fetch water, roundtrip	893	17.2	23.6
Presence of water at handwashing station	4076	94%	24%
Presence of soap at handwashing station	4076	59%	49%
Presence of water and soap at handwashing station	4076	56%	50%
Had any sanitation facility	4075	65%	48%
Had improved sanitation facility‡	4082	40%	49%
Open defecation (OD)	4075	35%	48%
Used shared toilet	4082	25%	43%
Child stools properly disposed of§	3068	86%	35%

*Finished floor defined as floor made of wood plans, palm/bamboo, parquet or polished wood, vinyl or asphalt strips, ceramic tiles, cement tiles or cement. Floor materials were classified by enumerator observation.
†Improved sources of drinking water include: piped water into dwelling/yard/plot, public tap or standpipe, tube well or borehole, protected dug well, protected spring, bottled water, and rainwater.
‡Improved sanitation facilities include: flush/pour flush toilet to a piped sewer system, septic tank or pit latrine, a ventilated improved pit latrine, a pit latrine with slab and a composting toilet.
§Proper disposal of children faeces consist of putting or rinsing stool into a sanitation facility or burying it; unsafe disposal of children faeces includes putting or rinsing stool into a drain or ditch, throwing it into garbage or leaving it in the open.

had an improved drinking water source and water source on site (85% and 78%, respectively), although the survey took place during the rainy season (May–October) so most households collected rainwater for drinking. Most households (94%) also had water at their home's handwashing station, but only 59% of homes had soap. Sixty-five per cent of households had access to any sanitation facility (including 25% with shared facilities), while only 40% of households had access to an improved sanitation facility. Although most of the pour/flush systems were recorded as improved systems that discharged into septic tanks or pit latrines (1971/1976 of pour/flush facilities), there was no record of how wastewater and sludges were managed, so we are unable to determine whether these facilities are safely managed per the Joint Monitoring Programme (JMP) classification scheme.[37] Most households (86%) properly disposed of child stools by burying stools (46%).

Table 3 summarises results from the secondary survey that captures community WASH practices irrespective of children in the household. Compared with households that had children (table 1), the community overall had less access to an improved drinking water source (72% vs 85%) but more access to an improved sanitation facility (46% vs 40%) and lower prevalence of open defecation practices (31% vs 35%). The community overall used shared toilets less frequently compared with households with children (10% vs 25%) and practiced safe methods of disposing children's stools more frequently than

Table 3 Community WASH variables, calculated using poststratification weights

Community WASH variables	N	%	SD (%)
Had improved sanitation facility*	5341	46%	31%
Open defecation	5341	31%	30%
Used shared toilet	5341	10%	16%
Child stools properly disposed of†	5321	93%	16%

*Improved sanitation facilities include: flush/pour flush toilet to a piped sewer system, septic tank or pit latrine, a ventilated improved pit latrine, a pit latrine with slab and a composting toilet.
†Proper disposal of children faeces consist of putting or rinsing stool into a sanitation facility or burying it; unsafe disposal of children faeces includes putting or rinsing stool into a drain or ditch, throwing it into garbage or leaving it in the open.

households with children (93% vs 86%); methods of stool disposal were qualified as 'safe' if the child's faeces was put into any toilet or latrine.[38] Overall, households with children appear to have poorer sanitation practices than the overall community.

Table 4 and figure 1 summarise pooled and age-stratified LAZ mean differences and the nutrition and WASH variables of interest. In the pooled analysis, we found breastfeeding to be negatively associated with growth (LAZ −0.16, 95% CI −0.27 to −0.05) and household presence of water and soap to be positively associated with growth (LAZ +0.10, 95% CI 0.03 to 0.16). In the age-stratified analysis, younger children were found to have different risk factors for growth faltering than older children. For children 1–6 months of age, household presence of soap and water was positively associated with length (+0.10 LAZ, 95% CI −0.02 to 0.22), and community-level improved drinking water and community-level shared sanitation were negatively associated with length (LAZ −0.28, 95% CI −0.51 to −0.05 compared with children in communities with no improved drinking water; LAZ −0.47, 95% CI −0.90 to −0.05 compared with children in communities with no shared sanitation). For children 6–12 months of age, household presence of soap and water was positively associated with length (+0.11 LAZ, 95% CI −0.02 to 0.25), and breastfeeding was negatively associated with growth (LAZ −0.62, 95% CI −1.01 to −0.23 compared with children who were not breast fed). For children 12–24 months of age, household-level improved drinking water was positively associated with growth (LAZ +0.13, 95% CI 0.00 to 0.28 compared with children in households with no improved drinking water); and breastfeeding was negatively associated with growth (LAZ −0.11, 95% CI −0.23 to 0.00 compared with children who were not breast fed).

Table 5 and figure 1 summarise pooled and age-stratified associations between stunting and the nutrition and WASH variables of interest. In the pooled analysis, we found household-level improved drinking water and household-level adequate disposal of children's stools to be protective against stunting (aPR 0.80, 95% CI 0.67

Table 4 Linear regression coefficient for association between nutrition and WASH variables and linear growth

	N	Unadjusted effect size (pooled)	N	Adjusted effect size (pooled)	N	Adjusted effect size (1–6 months)	N	Adjusted effect size (6–12 months)	N	Adjusted effect size (12–24 months)
Child-level indicators										
Currently breastfed*	3908	0.40 (0.30, 0.51)	3709	−0.16 (−0.27, -0.05)	1055	0.07 (−0.39, 0.54)	1110	−0.62 (−1.01, -0.23)	1564	−0.11 (−0.23, 0.00)
Minimum dietary diversity met*, †	3973	0.01 (−0.08, 0.10)	2421	0.05 (−0.03, 0.14)	–	n/a	1112	−0.01 (−0.15, 0.13)	1598	0.06 (−0.03, 0.16)
Minimum meal frequency met*, †	3984	0.05 (−0.07, 0.17)	2421	−0.01 (−0.13, 0.10)	–	n/a	1112	−0.02 (−0.20, 0.16)	1068	0.01 (−0.12, 0.14)
Household–level indicators										
Improved drinking water source*, ††	3975	0.05 (−0.06, 0.16)	3767	0.04 (−0.06, 0.13)	1063	−0.09 (−0.23, 0.05)	1110	0.04 (−0.16, 0.24)	1594	0.13 (−0.01, 0.28)
Presence of water and soap at handwashing*	3978	0.11 (0.03, 0.19)	3771	0.10 (0.03, 0.16)	1064	0.10 (−0.02, 0.22)	1110	0.11 (−0.02, 0.25)	1597	0.06 (−0.04, 0.16)
Proper disposal of child stool*, ¶	2994	−0.15 (−0.27,−0.02)	2843	0.05 (−0.07, 0.16)	622	−0.08 (−0.25, 0.10)	885	0.13 (−0.07, 0.33)	1336	0.10 (−0.13, 0.32)
Sanitation facility*	3977		3769		1065	n/a	1112	n/a	1592	n/a
Improved‡	–	0.16 (0.07, 0.25)	–	0.05 (−0.03, 0.14)	–	0.09 (−0.05, 0.24)	–	0.09 (−0.09, 0.27)	–	0.04 (−0.07, 0.16)
Shared	–	0.08 (−0.03, 0.20)	–	−0.01 (−0.13, 0.10)	–	0.01 (−0.17, 0.18)	–	−0.06 (−0.25, 0.14)	–	0.04 (−0.13, 0.20)
None (open defecation)	–	ref	–	ref	–	ref	–	ref	–	ref
Community–level indicators										
Improved drinking water source (village level)**, ††	3984	−0.13 (−0.26, 0.00)	3792	−0.13 (−0.26, 0.00)	1068	−0.28 (−0.51, −0.05)	1120	−0.24 (−0.48, 0.00)	1604	−0.07 (−0.25, 0.11)
Proper disposal of child stool (village level)¶, **	3970	0.04 (−0.19, 0.27)	3778	−0.01 (−0.23, 0.20)	1063	−0.18 (−0.53, 0.17)	1116	−0.41 (−0.94, 0.13)	1599	0.23 (−0.10, 0.55)
Improved sanitation facility (village level)‡, **	3984	0.10 (−0.02, 0.23)	3792	0.07 (−0.06, 0.19)	1068	0.08 (−0.14, 0.31)	1120	0.12 (−0.11, 0.36)	1604	0.08 (−0.10, 0.26)
Shared sanitation facility (village level)**	3984	−0.11 (−0.34, 0.12)	3792	−0.19 (−0.42,0.03)	1068	−0.47 (−0.90, −0.05)	1120	−0.24 (−0.64, 0.16)	1604	0.04 (−0.27, 0.34)
Open defecation (village level)**	3984	−0.08 (−0.21, 0.05)	3792	−0.03 (−0.16,0.10)	1068	−0.02 (−0.25, 0.22)	1120	0.02 (−0.22, 0.26)	1604	−0.12 (−0.30, 0.07)

*Adjusted for child gender, child age, child illness, maternal age, maternal education, household size and household wealth index quintile; clustered by village.
†Only children >6 months.
‡Improved sanitation facilities include: flush/pour flush toilet to a piped sewer system, septic tank or pit latrine, a ventilated improved pit latrine, a pit latrine with slab and a composting toilet.
¶Proper disposal of children faeces consist of putting or rinsing stool into a sanitation facility or burying it; inadequate disposal of children faeces includes putting or rinsing stool into a drain or ditch, throwing it into garbage or leaving it in the open.
**Adjusted for village-level covariates: % male, mean child age, % with illness, % breast fed and mean household wealth index quintile.
††Improved sources of drinking water include: piped water into dwelling/yard/plot, public tap or standpipe, tubewell or borehole, protected dug well, protected spring, bottled water and rainwater.

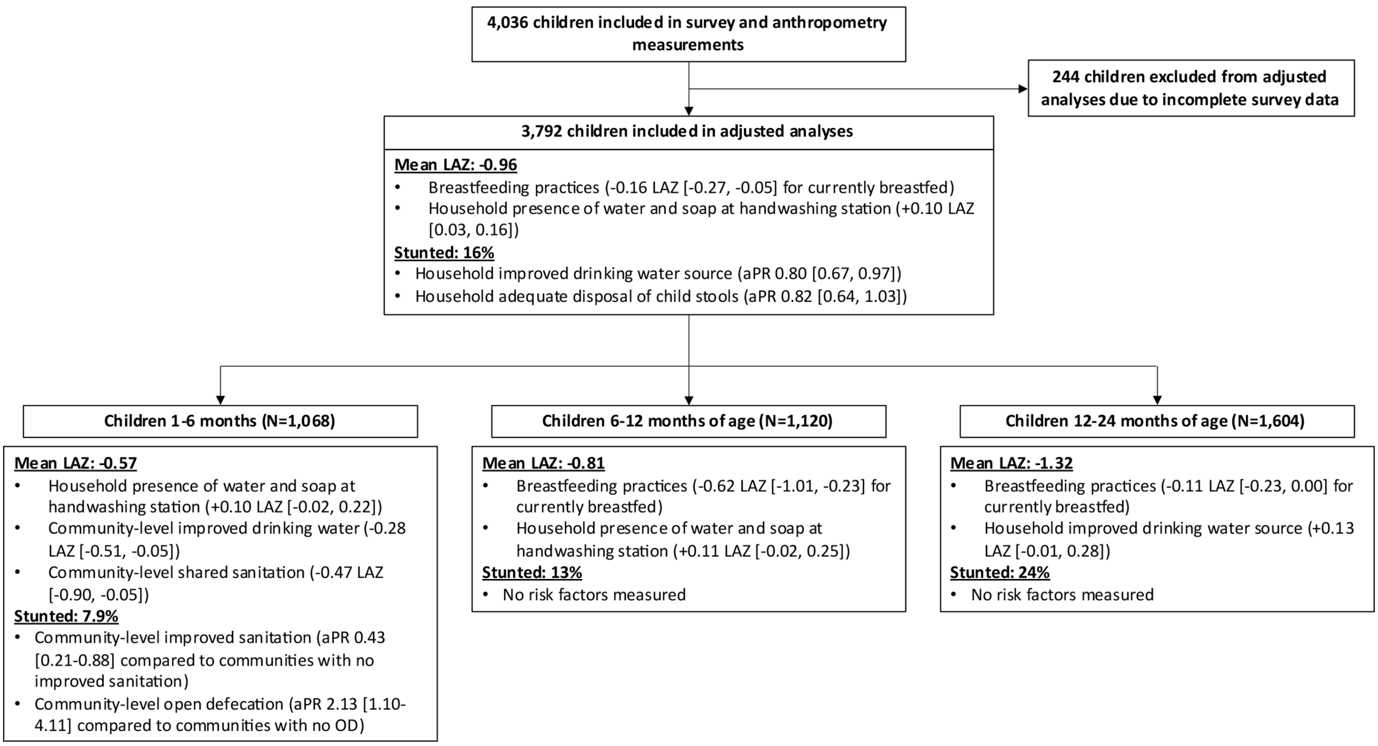

Figure 1 Flow chart summarising findings from pooled and subgroup analyses. LAZ, length-for-age z-score.

to 0.97 compared with children in households with no improved drinking water; and aPR 0.82, 95% CI 0.64 to 1.03 compared with children in households that did not practice adequate stool disposal methods); these associations were not measurably significant in any of the age strata in the age-stratified subgroup analyses. For children 1–6 months of age, community-level sanitation was found to be protective against stunting (aPR 0.43, 95% CI 0.21 to 0.88 compared with children in communities with no improved sanitation; aPR 2.13, 95% CI 1.10 to 4.11 compared with children in communities with no sanitation coverage); these associations were not measurably significant among children in older age strata.

In our supplemental analysis, we assessed the impact of village-level associations by evaluating village-level outcomes and found no statistically significant association between any nutrition or WASH variables and growth faltering or stunting (online supplemental information).

DISCUSSION

We examined household-level nutrition and WASH characteristics and community-level WASH infrastructure on early childhood linear growth in rural Cambodia. After adjustment for potential confounders, we found factors at the child, household and community levels that were associated with growth: breastfeeding was associated with faltered growth; and household use of an improved drinking water source, household's adequate disposal of child stools, and household presence of soap and water at the handwashing station were positively associated with growth among children 1–24 months of age. In our subgroup analyses, household presence of soap and water at the handwashing station were positively associated with growth among younger children (under 12 months of age), underscoring the potential role of good hygiene—including handwashing with soap and other practices made possible by more reliable water supply at the household level—in promoting optimal growth outcomes among children.[11 39–41] At the community level, high prevalence of open defecation and high prevalence of shared sanitation facilities—considered as suboptimal compared with individual household sanitation in international monitoring[42]—were each found to be negatively associated with growth for children under 6 months of age; notably, these associations were not measured in children older than 6 months of age. These findings are consistent with other studies reporting adverse health effects associated with shared sanitation facilities,[43 44] which may be less functional, less clean and more likely to have faeces and flies.[45] The growth associations from community-level sanitation factors is supported by the 'herd protection' plausibility[21 22] and suggest that caregiver WASH practices and exposures as possible routes of transmission for younger infants. Overall, our results are consistent with other observational studies reporting associations between WASH and reduced child undernutrition,[25 26 46–50] though such associations have not generally been realised in experimental trials.[51 52] Breastfeeding was associated with reduced length in both the pooled analysis and in the older subgroups (>6 months of age); however, other studies have observed that mothers may breastfeed longer if the child is smaller and wean early if the child is physically large.[53] No other

Table 5 Prevalence ratios for association between nutrition and WASH variables and stunting

	N	Unadjusted PR (pooled)	N	aPR (pooled)	N	aPR (1–6 months)	N	aPR (6–12 months)	N	aPR (12–24 months)
Child-level indicators										
Currently breast fed*	3908	0.61 (0.53, 0.70)	3709	1.10 (0.92, 1.32)	1055	0.82 (0.34, 1.98)	1090	1.82 (0.79, 4.22)	1564	1.10 (0.91, 1.32)
Minimum dietary diversity met*, †	3973	0.65 (0.56, 0.75)	3765	0.89 (0.78, 1.03)	–	n/a	1112	0.98 (0.71, 1.37)	1598	0.87 (0.74, 1.03)
Minimum meal frequency met*, †	3984	1.50 (1.29, 1.74)	3776	1.09 (0.93, 1.28)	–	n/a	1112	1.45 (0.94, 2.23)	1598	1.00 (0.82, 1.22)
Household–level indicators										
Improved drinking water source*, ††	3975	0.83 (0.69, 1.01)	3767	0.80 (0.67, 0.97)	1063	0.78 (0.48, 1.29)	1110	0.77 (0.53, 1.11)	1594	0.81 (0.65, 1.00)
Presence of water and soap at handwashing*	3978	0.97 (0.84, 1.11)	3771	0.94 (0.82, 1.08)	1064	0.86 (0.59, 1.25)	1110	0.82 (0.62, 1.10)	1597	1.05 (0.88, 1.26)
Proper disposal of child stool*, ¶	2994	1.13 (0.89, 1.44)	2843	0.82 (0.64, 1.03)	622	0.92 (0.52, 1.60)	885	0.77 (0.48, 1.23)	1336	0.82 (0.60, 1.12)
Sanitation facility*	3977	–	3769	–	1065	–	1112	–	1592	–
Improved‡	–	0.76 (0.65, 0.89)	–	0.93 (0.78, 1.11)	–	0.69 (0.44, 1.09)	–	0.95 (0.63, 1.43)	–	1.03 (0.84, 1.26)
Shared	–	0.87 (0.70, 1.07)	–	0.89 (0.72, 1.10)	–	0.84 (0.43, 1.62)	–	0.86 (0.53, 1.40)	–	1.00 (0.78, 1.29)
None (open defecation)	–	ref	–	ref	–	ref	–	ref	–	ref
Community–level indicators										
Improved drinking water source (village level)**, ††	3984	1.20 (0.94 to 1.53)	3792	1.20 (0.93, 1.55)	1068	1.36 (0.63, 2.95)	1120	1.57 (0.89, 2.76)	1604	1.09 (0.80, 1.48)
Proper disposal of child stool (village level)¶, **	3970	1.02 (0.67, 1.56)	3778	1.08 (0.70, 1.66)	1063	2.04 (0.60, 6.96)	1116	1.24 (0.43, 3.58)	1599	0.91 (0.55, 1.51)
Improved sanitation facility (village level)‡, **	3984	0.78 (0.63, 0.98)	3792	0.91 (0.71, 1.16)	1068	0.43 (0.21, 0.88)	1120	1.14 (0.67, 1.94)	1604	1.00 (0.75, 1.34)

Continued

Table 5 Continued

	N	Unadjusted PR (pooled)	N	aPR (pooled)	N	aPR (1–6 months)	N	aPR (6–12 months)	N	aPR (12–24 months)
Shared sanitation facility (village level)**	3984	1.04 (0.65, 1.66)	3792	1.09 (0.70, 1.72)	1068	1.53 (0.44, 5.31)	1120	0.61 (0.20, 1.83)	1604	1.19 (0.71, 2.01)
Open defecation (village level)**	3984	1.29 (1.02, 1.63)	3792	1.11 (0.87, 1.42)	1068	2.13 (1.10, 4.11)	1120	1.02 (0.58, 1.77)	1604	0.98 (0.73, 1.32)

*Adjusted for child gender, child age, child illness, maternal age, maternal education, household size and household wealth index quintile; clustered by village.
†Only children >6 months.
‡Improved sanitation facilities include: flush/pour flush toilet to a piped sewer system, septic tank or pit latrine, a ventilated improved pit latrine, a pit latrine with slab and a composting toilet.
¶Proper disposal of children faeces consist of putting or rinsing stool into a sanitation facility or burying it; inadequate disposal of children faeces includes putting or rinsing stool into a drain or ditch, throwing it into garbage or leaving it in the open.
**Adjusted for village-level covariates: % male, mean child age, % with illness, % breast fed and mean household wealth index quintile.
††Improved sources of drinking water include: piped water into dwelling/yard/plot, public tap or standpipe, tubewell or borehole, protected dug well, protected spring, bottled water and rainwater.
PRs, prevalence ratios.

measure of feeding practices (dietary diversity, meal frequency and minimum acceptable diet) was associated with growth outcomes in this study.

The most recent CDHS dataset from 2014 (data collection between June–November 2014) reported a mean LAZ of −1.10 (SD 1.52) and 26% (SD 44%) of children stunted among children under 24 months the same provinces (Pursat, Battambang and Siem Reap), suggesting greater growth faltering in previous surveys compared with ours. These estimates are consistent with the trend of rapidly improving child growth that rural Cambodia has been experiencing in the past 20 years as indicated in CDHS data. While limited to rural communities in 3 of 13 provinces of Cambodia, our findings are also consistent with CDHS findings of patterns of preferred sanitation facilities: Cambodian families prefer to move directly from open defecation to 'improved' sanitation facilities (pour-flush, with a cleanable slab) rather than incrementally moving up the sanitation ladder (ie, traditional pit latrines).[54]

Though the critical window for interventions to increase child linear growth is in the first 2 years of life, most studies measuring the prevalence of stunting and linear growth have examined older children, typically under 5 years of age. In older children, growth deficits have generally shown a stronger apparent correlation with WASH characteristics in observational studies across geographies. Studies from Peru and Indonesia among children under 2 and 3 years of age, respectively, found household sanitation to be associated with taller children.[47 48] Similarly, a meta-analysis that captured data from 70 low-income and middle-income countries found household access to an improved sanitation facility to be associated with lower risk of stunting (OR of 0.92)[50] among children under 5 years of age. In Cambodia, previous observational studies reported strong associations between nutrition and WASH variables on child linear growth and stunting for children. Consistent with our findings, one study using pooled CDHS data from 2000 to 2005 found no association between feeding indicators (dietary diversity and meal frequency) and child growth outcomes in children aged 6–23 months in Cambodia.[55] Another study using pooled CDHS data from 2000 to 2010 found household access to an improved sanitation facility to be associated with a lower prevalence of stunting among children under 5 years (PR 0.82, 95% CI 0.69 to 0.96)[26]; the same study performed a subgroup analysis on feeding practices and child growth and did not find any statistically significant associations between exclusive breastfeeding (<6 months) and meal frequency (6–23 months) on stunting. Differences in estimates may be explained by differences in study design and methods, including examining different age strata, variability in measuring risk factors, study setting (eg, rural vs urban) and timing: Cambodia has experienced rapid growth and development in recent years,[56] with accompanying substantial changes in the prevalence of risk factors that may influence growth outcomes in children.

Consistent with findings from this study, observational studies of older children in Ecuador, Mali and India that have found community-level sanitation to be associated with child growth that may be greater than the effect of household-level sanitation.[21 23 57–59] Similarly, a meta-analysis that included data from 93 countries found that children under 5 years of age living in communities with high sanitation coverage and no household sanitation facility had lower odds of being stunted than children living in communities with low coverage and with household sanitation, further signalling the role of community.[49] In Cambodia, a previous study of children under 5 years of age concluded that reduction in children's exposure to open defecation between 2005 and 2010 accounted for much or all of the increase in average child height.[25] Such effects may not be discernible in children under 24 months of age but may be apparent in older children as growth trajectories manifest beyond early childhood.

This study adds to a growing body of evidence suggesting that the relationship between water and sanitation infrastructure, hygiene, nutrition and growth outcomes is complex, variable and context specific.[52] Several recent nutrition and WASH trials have been designed and implemented assuming a causal framework linking improved nutrition and WASH to improved child health outcomes, including linear growth and stunting. A systematic review identified five randomised controlled trials that found a small but statistically meaningful effect among children under 5 years of age[10]; another systematic review of sanitation intervention trials found similar, modest effects of sanitation on nutritional status among children of varying age groups up to school-age (LAZ +0.08, 95% CI 0.00, 0.16).[60] The WASH Benefits trials in Kenya and Bangladesh reported growth gains attributable to integrated nutrition and sanitation programming compared with control among children among children under 30 months of age, although these observed gains were likely to have been attributable to nutritional improvements alone since there were no measurable added benefits from adding WASH programming to nutrition.[7 8] Similarly, the SHINE trial in Zimbabwe reported beneficial growth effects among children approximately 18 months of age from nutrition programming but no added benefits of integrating WASH with nutrition programming.[20] Overall, the available evidence for WASH's role in supporting growth outcomes is mixed, warranting a closer examination of underlying mechanisms driving child growth and a need to expand the scope of transformational WASH interventions that most effectively separate the whole families from faecal exposures.

Our results should be considered alongside the limitations of our methods. The survey data were self-reported and therefore open to recall biases, including courtesy bias (responding in ways perceived to be more pleasing to interviewers), desirability bias (over-reporting of positive perceptions) and acquiescence bias (answering in the affirmative). As a cross-sectional study, we were unable to assess directionality of associations or infer causality between measured variables. For example, the observed association between growth faltering and ongoing breastfeeding may erroneously implicate breastfeeding as a cause of growth faltering, when it is more probably reflective of a compensatory response to underweight status.[53] Village-scale estimates of coverage may or may not be reflective of a child's exposure to the environment. Younger children, particularly under 6 months of age, may receive particular attention and care and different child-feeding practices; the survey used for this study was not designed to delineate exclusive breastfeeding from general breastfeeding. We are limited in our ability to link direct primary caretaker-to-child practices to childhood growth because the associations measured link general household practices growth. Finally, this study only captures exposures at one point in time, but longer term effects of these exposures may not be apparent until later in life.

CONCLUSION

In rural Cambodia, water, sanitation and hygiene behaviours were associated with growth faltering among children under 24 months of age. Community-level sanitation factors were positively associated with growth, particularly for infants under 6 months of age. We should continue to make effort to: investigate the relationships between water, sanitation, hygiene and human health; expand WASH access for young children; and integrate hygiene education and interventions with other effective interventions in programmes that aim to support maternal and child health where risks of undernutrition are high.

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Patient consent for publication Consent obtained from parent(s)/guardian(s)

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