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Effect of water, sanitation and hygiene interventions alone and combined with nutrition on child growth in low and middle income countries: a systematic review and meta-analysis

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ABSTRACT

Objective This study aimed to provide clarification on the benefits of water, sanitation and hygiene (WASH) alone separately and combined with nutrition in improving child growth outcomes.

Design Systematic review and meta-analysis.

Methods We conducted a systematic review using the Preferred Reporting Items for Systematic Review and Meta-Analyses guidelines. PubMed, MEDLINE, EMBASE, Scopus, Cochrane Library, Web of Science and Science Direct were searched in May 2018 and last updated in April 2019. We included studies that reported WASH interventions alone separately or combined with nutrition. Fixed and random-effects models were used to estimate pooled effect in mean difference (MD). Heterogeneity and publication bias statistics were performed.

Results A total of 18 studies were included: 13 cluster randomised controlled trials (RCTs) and 5 non-randomised controlled trials (non-RCTs). Non-RCTs showed effect of WASH interventions alone on height-for-age z-score (HAZ) (MD=0.14; 95% CI 0.08 to 0.21) but RCTs did not. WASH alone of non-RCTs and RCTs that were delivered over 18–60 months indicated an effect on HAZ (MD=0.04; 95% CI 0.01 to 0.08). RCTs showed an effect for children <2 years (MD=0.07; 95% CI 0.01 to 0.13). Non-RCTs of WASH alone and those that included at least two components, improved HAZ (MD=0.15; 95% CI 0.07 to 0.23) but RCTs did not. WASH alone of non-RCTs and RCTs separately or together showed no effect on weight-for-age z-score (WAZ) and weight-for-height z-score (WHZ). Combined WASH with nutrition showed an effect on HAZ (MD=0.13; 95% CI 0.08 to 0.17) and on WAZ (MD=0.09; 95% CI 0.05 to 0.13) and was borderline on WHZ.

Conclusions WASH interventions alone improved HAZ when delivered over 18–60 months and for children <2 years. Combined WASH with nutrition showed a strong effect on HAZ and WAZ and a borderline effect on WHZ. Integrated WASH with nutrition interventions may be effective inimproving child growth outcomes.

Strengths and limitations of this study

- ► This study reviewed evidence from studies that were conducted in low-income and middle-income countries following the guidelines of Preferred Reporting Items for Systematic Review and Meta-Analyses.
- ► We explored data from both randomised controlled trials and non-randomised studies.
- ► Sources of heterogeneity were assessed using subgroup analyses and meta-regressions based on prior identified factors.
- ► As few studies were included in the meta-analysis, this study could not confirm that the effect of water, sanitation and hygiene (WASH) plus nutrition versus nutrition or WASH on child growth may be due to nutrition only.
- ► Most of the methodological quality of included studies was deemed very low, low and medium, that is, none of the included studies have low risk of bias.

INTRODUCTION

Child growth failure (CGF), which is known as under-5 stunting, wasting and being underweight, is a specific subset of child undernutrition that excludes micronutrient deficiencies.[1] Estimations of stunting, wasting and being underweight can serve as a comprehensive assessment of CGF. CGF (height-for-age z-score (HAZ), weight-for-age z-score (WAZ) and weight-for-height z-score (WHZ) below −2 SD) based on Child Growth Standards of the WHO begins in the early life of a child.[2 3]

Water, sanitation and hygiene (WASH) interventions refer to the entire suite of activities on water quality and quantity, sanitation, handwashing with soap, food and environmental hygiene. In 2015, an estimated 663 million people worldwide had no access to improved drinking water sources[4] and 1.9 billion people relied on drinking water that was faecally contaminated.[5] Similarly, 2.4 billion people, that is one-third of the world's population, were estimated to lack access to improved sanitation facilities[6] and 13% practised open defecation.[4] Sub-Saharan Africa and South Asia continue to have the lowest sanitation coverage.[4] Freeman *et al* reported that only 19% of people around the world wash their hands with water and/or soap after contact with excreta.[7]

Recent evidence found there may be an effect of WASH interventions on CGF.[8 9] However, the exact mechanism and evidence for how WASH interventions might improve child growth are still under consideration.[2] Some studies have found no benefits of WASH interventions in improving child growth[3] and in contrast some studies found small effects.[10 11] Combined WASH components have improved HAZ (mean difference (MD)=0.22) and reduced the risk of stunting (Relative Risk (RR) =0.87).[12] A previous study suggested that universal coverage (90%) of nutrition interventions in areas with a high burden of CGF would only decrease stunting by 20%.[13] Inflammation caused by environmental enteric dysfunction due to inadequate WASH exposure[14] may explain why nutritional interventions are often unsuccessful.[15 16] Current interventions are examining the effect of WASH alone and combined with nutrition on child growth outcomes. To date, few meta-analyses have been conducted to examine the effect of WASH alone .[11 12 17] We have included recently published trials with well-designed methods in the current review. To our knowledge, there is no study which has reviewed the effect of combined WASH with nutrition interventions on child growth. The current review aims to review the effect of WASH interventions alone separately and when combined with nutrition on child growth.

METHODS

Search strategy and screening

In this review, we followed the procedures of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2009 Checklist) statement (http://www.prisma-statement.org/) (online supplementary checklist 1).[18] We used the following search terms: 'Child,' 'Infant,' 'Preschool,' 'Growth,' 'Stunting,' 'Wasting,' 'Underweight,' 'Undernourished,' 'Height-for-age,' 'Water,' 'Sanitation,' 'Hygiene,' 'Handwashing,' and 'Water disinfection.' PubMed, MEDLINE, EMBASE, Scopus, Cochrane Library, Web of Science and Science Direct were searched for articles in May 2018 and last updated in April 2019 for new articles. Additional search engines Google and Google Scholar were searched for grey literature and PhD dissertations. Furthermore, we hand-searched citations of key literature to identify relevant articles. This review details the search strategy within the body of the review, while the detail of search terms is provided in the supplementary file (online supplementary table 1). The identified articles were exported to citation manager EndNote V.X8 reference software and duplicates were discarded.

Inclusion criteria included randomised controlled trials and non-RCT studies, interventions on WASH alone (individual or combined) or combined with nutrition, reported mean and SD or error for z-score of child growth outcomes in both arms, children under-5 years of age, written in English and no limit on year of publication. Reporting child growth and malnutrition using summary measure such as mean and SD z-score has an advantage over the cut-off-based prevalence (stunted, underweight and wasted) approach.[19] As such, we have considered reports with mean HAZ, WAZ and WHZ only. Searched articles were screened in three stages—by going through the titles, then abstract and finally the full text. We used a PRISMA flow diagram (http://www.prisma-statement.org/)[18] to present the results of identified articles.

Data extraction and quality assessment

The primary author (TB) conceived the idea, searched and screened all relevant articles, extracted the data, performed analysis, assessed quality and drafted the manuscript. PR and BR checked the screened and excluded studies by the primary author and edited the manuscript. Mutual consensus among authors for excluded studies was sought through discussion when disagreements arose between authors. Data extraction and assessments were performed using the Cochrane Effective Practice and Organization of Care (EPOC) (https://epoc.cochrane.org)[20] approach. Quality evaluation criteria were categorised into two broad parts. Part I: general domains which comprised information such as study design, participant information, component of interventions and outcome measures with overall weighting of 40%. Points were given for each item based on the level of adequate information and the overall score was added to the maximum of 100 points.

We assigned greater weight (60%) for Part II (risk of bias reduction) which assessed detailed quality of the research methods. We used item questions which are described in Cochrane EPOC risk of bias tools[20] for studies with separate control groups with few items added. About 10-item questions were used in the current study. All included studies were rated against each question as having either a low risk, unclear risk or high risk of bias. Scores were assigned for each item question from 0 to 10 points and the overall points add up to a maximum of 100 points. For an item, 10 points were allocated for adequate methods (low risk), 5 points for methods that were inadequate (unclear risk) and 0 if the methods were not reported (high risk). To judge the quality of each included study, a weighted mean[21 22] was calculated for each included study using scores as well as weights from both Part I and Part II. The overall quality was judged to be very low quality (weighted mean (WM)=0–54.9), low quality (WM=55–64), moderate quality (WM=65–74), good quality (WM=75 to 84) and high quality (WM=85–100).

Data analysis and synthesis

We stored and analysed data using the Cochrane Community Review Manager Software (RevMan V.5.3 for Windows).[23] Pooled results were reported using mean difference with

95% CI as well as forest plots created using both fixed and random-effects models. Subgroup analyses were performed for WASH interventions alone based on age, length of interventions, geographical regions and types of interventions. Heterogeneity between studies was checked using Cochrane Q-test statistics and quantified using I^2 statistics (ie, I^2=100% (Q-DF)/Q, where Q is Cochrane's χ^2 test statistics and DF is degree of freedom).[24] Heterogeneity was classified as I^2: 0%–40% minimal, 30%–60% moderate, 50%–90% substantial and 90%–100% considerable. Meta-regression and statistical tests for publication bias were performed by Stata V.11.2 SE.

We explored publication bias by checking asymmetry of funnel plots. Egger's test statistic was used to check significant publication bias. Sensitivity analysis was performed by removing each study step-by-step in forest plots as well as by checking whether fixed and random-effects models produced different pooled estimates. We separately added sources of heterogeneity through potential moderators and investigated their influence on the effect measures using meta-regression models.

Patient and public involvement

Patients and the public were not involved in the design or conduct of the study.

RESULTS

Description of studies

Of all searched 3561 articles, 1312 were removed due to duplication. Based on titles and abstracts of 2249 articles, 2186 were excluded after comparing titles and information reported in the abstracts against the inclusion criteria of the current review. The full text of 63 articles were assessed for eligibility which resulted in excluding 43 studies. We contacted four authors of the excluded studies on the basis that if requested data were provided, those studies would fulfil the criteria to be included in the review. However, none of the contacted authors responded to our request. The remaining 20 studies satisfied the inclusion criteria set for a study to be included in the current review. We contacted authors of seven included studies for additional information and we received responses from five authors.[25–29] Finally, we included 18 studies for quantitative synthesis, of which 15 were peer reviewed and 3 were World Bank working reports. Based on the exclusion criteria, all included studies were conducted in low-income and middle-income countries.

Duration of interventions ranged from 6 to 60 months: 6 months[30–32]; 12 months[27 29 33 34]; 18 months[35–37]; 21 months[38]; 24 months[26 39–41]; 30 months[28]; 36 months[42] and 60 months.[25 43] All interventions considered children <5 years of age. Interventions were provided based on the presence of under-5 years of age and/or pregnant women in the selected households and the sample size raged from 88[31] to 4360[38] (figure 1).

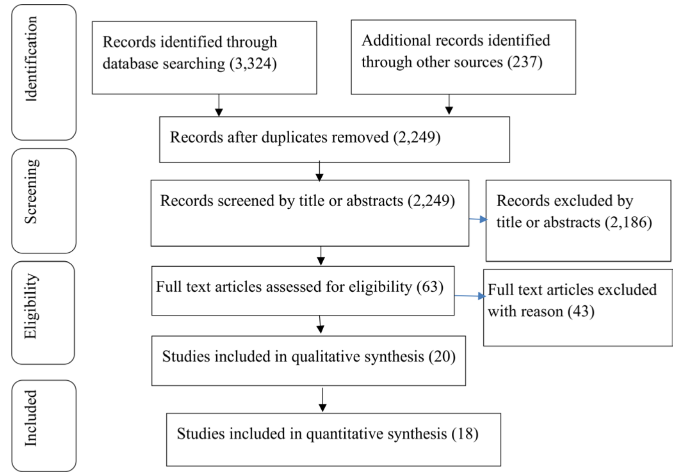

Figure 1 The Preferred Reporting Items for Systematic Review and Meta-Analyses flow diagram.

Description of interventions and controls

Interventions

Included interventions were those with at least one component of WASH or combined with nutrition. WASH interventions aimed to improve water quality, water supply, improve sanitation and handwashing. Method of delivery could include behaviour change via education, such as total sanitation campaign and handwashing promotion, more direct interventions such as drinking water disinfection, latrine renovation or construction, or the combination of both behavioural change and direct interventions. Combined WASH with nutrition interventions included any of the above plus young child feeding practices.

Controls

Controls included study participants without any of the above interventions (ie, no water disinfection, continued to practise open defecation, no handwashing promotion and stations, no WASH behavioural change via education and no nutrition intervention programmes). The description of interventions for the included studies is summarised in table 1.

Height-for-age

This section presents pooled estimates of WASH interventions alone regardless of the number of WASH components that were implemented. WASH interventions alone were shown to influence HAZ in the pooled effect estimate of non-RCTs (MD=0.14; 95% CI 0.08 to 0.21, p=0.001). Of five non-RCTs, two[39 43] showed an increased effect on HAZ (MD=0.22; 95% CI 0.12 to 0.32) and (MD=0.19; 95% CI 0.46 to 1.36) while the other three did not,[25 31 42] with substantial heterogeneity (I^2=81%). In the RCTs, only one[35] showed evidence of an effect on HAZ (MD=0.17; 95% CI 0.07 to 0.27) and the pooled estimate was not significant (MD=0.00; 95% CI −0.03 to 0.04), with moderate heterogeneity (I^2=51%). The overall estimate of non-RCT and RCT studies together showed no

Table 1 Characteristics of included studies in the meta-analysis

Author, year/ quality of evidence	Design	Country	Setting	Population	WASH alone and/or combined with nutrition	Outcome	Effect size MD	95% CI
Arnold *et al*, 2010 Quality: very low[25]	Non-RCT	India	Rural	Children <5 years	Water supply and improvements+sanitation and hygiene behaviour change	HAZ	−0.04	−0.35 to 0.30
						WAZ	−0.05	−0.26 to 0.18
						WHZ	−0.10	−0.19 to 0.10
Arnold *et al*, 2009 Quality: very low[42]	Non-RCT	Guatemala	Rural	Children <5 years	Water boiling, water solar disinfection and chlorination using dilute beach+handwashing promotions using soap or detergent and scrubbing	HAZ	0.04	−0.31 to 0.33
						WAZ	−0.05	−0.33 to 0.21
						WHZ	−0.07	−0.25 to 0.12
Bowen *et al*, 2012 Quality: low[30]	RCT	Pakistan	Rural	Children <5 years	Handwashing promotion with soap flocculent-disinfectant and sodium hypochlorite solution for drinking water treatment	HAZ	0.08	−0.29 to 0.27
						WAZ	−0.06	−0.27 to 0.17
Briceño *et al*, 2015 Quality: low[29]	RCT	Tanzania	Rural	Children <5 years	Total sanitation and sanitation marketing+handwashing with soap	HAZ	−0.01	−0.12 to 0.10
						WAZ	−0.08	−0.15 to 0.00
Cameron *et al*, 2013 Quality: medium[26]	RCT	Indonesia	Rural	Children <5 years	Total sanitation and sanitation marketing (community-led total sanitation+sanitation marketing+enabling environment)	HAZ	0.01	−0.01 to 0.03
						WAZ	0.03	−0.09 to 0.15
						WHZ	0.06	−0.06 to 0.18
Clasen *et al*, 2014 Quality: good[27]	RCT	India	Rural	Children <5 years	Latrine promotion and construction which combines social mobilisation with post hoc subsidy	HAZ	−0.01	−0.22 to 0.02
						WAZ	0.02	−0.04 to 0.08
Du Preez *et al*, 2011 Quality: medium[33]	RCT	Kenya	Pre-urban and rural	Children<5 years	Water disinfection using solar disinfection and chlorination	HAZ	0.11	−0.19 to 0.41
						WAZ	−0.01	−0.23 to 0.21
						WHZ	−0.11	−0.30 to 0.08
Fenn *et al*, 2012 Quality: low[43]	Non-RCT	Ethiopia	Rural	Children <5 years	Hygiene educational, free drug provision, free primary healthcare services, material provisions for pit latrines and safe water sources construction.	HAZ	0.33	0.08 to 0.59
Galiani *et al*, 2012 Quality: very low[28]	RCT	Peru	Rural	Children <2 years	Handwashing promotion using mass media plus direct consumer contact	HAZ	−0.02	−0.24 to 0.19
						WAZ	−0.01	−0.23 to 0.20
						WHZ	0.06	−0.11 to 0.22

Continued

Table 1 Continued

Author, year/ quality of evidence	Design	Country	Setting	Population	WASH alone and/or combined with nutrition	Outcome	Effect size MD	95% CI
Humphrey *et al*, 2019 Quality: good[37]	RCT	Zimbabwe	Rural	Pregnant women	Behaviour change modules delivery, standard of care messages, information dissemination on WASH and child feeding, latrine construction+handwashing stations+monthly supply of soap and chlorine+child feeding nutrient-rich foods+lipid-based nutrient	HAZ	0.06	−0.01 to 0.12
						WAZ	0.00	−0.06 to 0.06
						WHZ	−0.04	−0.11 to 0.03
Langford *et al*, 2011 Quality: very low[31]	Non-RCT	Nepal	Urban Slum	Children 3–12 months	Handwashing promotion	HAZ	−0.26	−0.66 to 0.13
						WAZ	−0.19	−0.62 to 0.23
						WHZ	0.09	−0.23 to 0.42
Lin *et al*, 2013 Quality: very low[39]	non-RCT	Bangladesh	Rural	Children <4 years	Education on water, sanitation and handwashing	HAZ	0.54	0.06 to 1.01
						WAZ	0.04	−0.48 to 0.55
						WHZ	−0.19	−0.61 to 0.24
Luby *et al*, 2018 Quality: good[40]	RCT	Bangladesh	Rural	Pregnancy in first two trimester and children <3 years	Individual water, sanitation and hygiene and combined WASH and WASH+nutrition	HAZ	0.02	−0.09 to 0.19
							0.13	0.02 to 0.24*
						WAZ	0.00	−0.09 to 0.10
							0.13	0.04 to 0.22*
						WHZ	0.00	−0.10 to 0.11
							0.09	0.00 to 0.18*
Muhoozi *et al*, 2017 Quality: medium[32]	RCT	Uganda	Rural	Children 20–24 months	Combined nutrition with simulation, sanitation and hygiene education	HAZ	0.10	−0.17 to 0.36*
						WAZ	0.01	−0.27 to 0.29*
						WHZ	−0.05	−0.33 to 0.22*
Nair *et al*, 2017 Quality: medium[36]	RCT	India	Rural	Pregnancy in third trimester and children <2 years	Counselling on maternal nutrition, growth promotion for children through young child feeding, illness prevention, education on water, sanitation and hygiene	HAZ	0.11	−0.01 to 0.23*
						WAZ	0.07	−0.02 to 0.16*
						WHZ	0.02	−0.08 to 0.11*
Null *et al*, 2018 Quality: good[41]	RCT	Kenya	Rural	Women in second or third trimester and children 6–24 months	Individual water, sanitation and hygiene or combined WASH intervention and combined with nutrition	HAZ	−0.03	−0.14 to 0.08
							0.16	0.05 to 0.27*
						WAZ	−0.02	−0.12 to 0.08
							0.14	0.04 to 0.25*
						WHZ	−0.02	−0.10 to 0.07
							0.09	0.00 to 0.19*

Continued

Table 1 Continued

Author, year/ quality of evidence	Design	Country	Setting	Population	WASH alone and/or combined with nutrition	Outcome	Effect size MD	95% CI
Patil *et al*, 2014 Quality: medium[38]	RCT	India	Rural	Children <5 years	Total sanitation campaign	HAZ	−0.04	−0.22 to 0.14
						WAZ	−0.09	−0.25 to 0.06
						WHZ	0.03	−0.14 to 0.20
Pickering *et al*, 2015 Quality: medium[35]	RCT	Mali	Rural	Children <5 years	Community-led total sanitation	HAZ	0.24	0.09 to 0.40
						WAZ	0.16	0.01 to 0.31

*Results of WASH+nutrition.
HAZ, Height-for-age z-score; I, Intervention; MD, mean difference; non-RCT, an experimental study comparing an intervention and control group, where the allocation method was not random; RCT, randomised controlled trial; WASH, water, sanitation and hygiene; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score.

statistically significant effect on HAZ (MD=0.03; 95% CI −0.01 to 0.06) (figure 2).

Subgroup analysis of children aged ≤2 years in the intervention group showed an increase in HAZ (MD=0.07; 95% CI 0.01 to 0.13, p=0.02) but not for children aged <5 years (MD=0.05; 95% CI −0.00 to 0.11) (table 2) and (online supplementary figure 1). WASH interventions alone, that were delivered over 18–60 months, showed a positive effect on children's HAZ (MD=0.04; 95% CI 0.01 to 0.08, p=0.02). Non-RCTs indicated a stronger effect (MD=0.15; 95% CI 0.07 to 0.23, p=0.0003) compared with RCTs (MD=0.02; 95% CI −0.02 to 0.07). WASH interventions alone in sub-Saharan Africa has increased HAZ (MD=0.06; 95% CI 0.01 to 0.10, p=0.01).

Individual WASH components effect on HAZ

We also examined the effect of individual WASH components on HAZ for water, sanitation and handwashing separately. None of the individual interventions showed improvement in HAZ: water only interventions (MD=−0.06; 95% CI: −0.13 to 0.01); sanitation only interventions (MD=−0.01; 95% CI: −0.10 to 0.08); and handwashing only interventions (MD=−0.06; 95% CI: −0.16 to 0.04) (plots not shown).

Combined WASH components effect on HAZ

We examined the effect of integrated WASH using studies that included at least two components (i.e., water, sanitation and handwashing). The pooled estimate from non-RCT studies showed an effect on HAZ (MD=0.15; 95% CI 0.07 to 0.23, p=0.0003) compared with RCTs (MD=−0.02; 95% CI −0.07 to 0.03). The overall pooled estimate from non-RCTs and RCTs together, with substantial heterogeneity (I^2=76%), showed no effect on HAZ (MD=0.02; 95% CI −0.02 to 0.07) (figure 3).

Combined WASH with nutrition interventions effect on HAZ

Five RCT studies reported combined WASH with nutrition versus control.[32 36 37 40 41] We compared intervention groups which received WASH plus nutrition versus nutrition (MD=−0.01; 95% CI −0.13 to 0.12) and WASH plus nutrition versus WASH (MD=18; 95% CI 0.12 to 0.25, p<0.001). Strong evidence of the effect on HAZ was indicated in groups that received WASH plus nutrition versus no-WASH plus no-nutrition (MD=0.13; 95% CI 0.08 to 0.17, p<0.001), with no evidence of heterogeneity (I^2=0%). One study[32] found no effect of combined WASH with nutrition interventions versus control on HAZ (MD=0.10; 95% CI −0.08 to 0.28) (figure 4).

Weight-for-age

Regardless of WASH components included in the study, data on WAZ were reported in 4 non-RCTs and 11 RCTs which were included in the meta-analysis. Of the non-RCTs, only one study[39] showed a significant effect on WAZ (MD=0.42; 95% CI 0.02 to 0.82) and the pooled estimate was non-significant (MD=−0.01; 95% CI −0.16 to 0.14), with moderate heterogeneity (I^2=46%). Only one[35] of the 11 RCTs showed a positive effect on WAZ (MD=0.09;

Study or Subgroup	WASH intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
1.1.1 Non-RCT								
Arnold 2009	-2.14	1.6	453	-2.18	1.88	424	2.0%	0.04 [-0.19, 0.27]
Arnold 2010	-2	1.69	974	-1.96	1.69	995	4.7%	-0.04 [-0.19, 0.11]
Fenn 2012	-2.12	1.15	863	-2.34	1.17	1036	9.6%	0.22 [0.12, 0.32]
Langford 2011	-1.82	0.9	45	-1.69	1.06	43	0.6%	-0.13 [-0.54, 0.28]
Lin 2013	-1.66	1.15	66	-2.57	1.33	53	0.5%	0.91 [0.46, 1.36]
Subtotal (95% CI)			**2401**			**2551**	**17.3%**	**0.14 [0.06, 0.21]**
Heterogeneity: Chi² = 21.29, df = 4 (P = 0.0003); I² = 81%								
Test for overall effect: Z = 3.46 (P = 0.0005)								
1.1.2 RCT								
Bowen 2012	-1.17	1.13	301	-1.09	1.08	160	2.4%	-0.08 [-0.29, 0.13]
Briceno 2015	-1.95	1.25	1291	-1.95	1.25	1323	11.4%	0.00 [-0.10, 0.10]
Cameron 2013	-1.71	1.04	1045	-1.72	1.36	1045	9.7%	0.01 [-0.09, 0.11]
Clasen 2014	-1.56	1.11	350	-1.36	1.22	337	3.4%	-0.20 [-0.37, -0.03]
Du Preez 2011	-0.74	1.65	275	-0.85	1.89	250	1.1%	0.11 [-0.19, 0.41]
Galiani 2012	-1.34	2.02	765	-1.31	2.19	711	2.3%	-0.03 [-0.25, 0.19]
Humphrey 2019	-1.61	1.07	914	-1.57	1.08	878	10.6%	-0.04 [-0.14, 0.06]
Luby 2018	-1.76	1.01	579	-1.79	1.01	1103	10.2%	0.03 [-0.07, 0.13]
Null 2018	-1.59	1.05	719	-1.54	1.11	1535	11.7%	-0.05 [-0.14, 0.04]
Patil 2014	-2.19	1.87	2175	-2.16	1.87	2185	8.5%	-0.03 [-0.14, 0.08]
Pickering 2015	-1.6	1.2	1283	-1.77	1.2	1132	11.4%	0.17 [0.07, 0.27]
Subtotal (95% CI)			**9697**			**10659**	**82.7%**	**0.00 [-0.03, 0.04]**
Heterogeneity: Chi² = 20.55, df = 10 (P = 0.02); I² = 51%								
Test for overall effect: Z = 0.17 (P = 0.86)								
Total (95% CI)			**12098**			**13210**	**100.0%**	**0.03 [-0.01, 0.06]**
Heterogeneity: Chi² = 51.27, df = 15 (P < 0.00001); I² = 71%								
Test for overall effect: Z = 1.60 (P = 0.11)								
Test for subgroup differences: Chi² = 9.43, df = 1 (P = 0.002), I² = 89.4%								

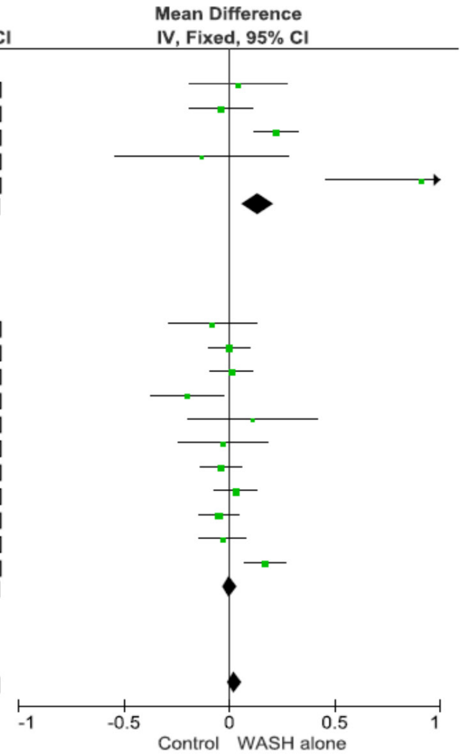

Figure 2 Forest plot of water, sanitation and hygiene (WASH) versus control comparison for outcome height-for-age z-score. RCT, randomised controlled trial.

95% CI 0.01 to 0.17) and the pooled estimate of non-RCTs and RCTs together was non-significant (MD=−0.02; 95% CI −0.05 to 0.00) with low heterogeneity (I^2=30%) (online supplementary figure 2). Subgroup analysis of the overall pooled estimate did not show evidence of an effect on WAZ for children<2 years of age, but one study[35] showed evidence of an effect (MD=0.15; 95% CI 0.04 to 0.26) compared with children <5 years (MD=0.09; 95% CI 0.01 to 0.17). WASH interventions alone showed a negative effect on WAZ in the Southern Asia region (MD=−0.04; 95% CI −0.10 to −0.01) (table 2).

Combined WASH with nutrition interventions effect on WAZ

We included five RCT studies which reported combined WASH with nutrition versus control.[32 36 37 40 41] Combined WASH with nutrition interventions improved WAZ (MD=0.09; 95% CI 0.05 to 0.13, p<0.001) with minimal heterogeneity (I^2=2%). However, two studies[32 36] did not show a positive effect (figure 5). We found only three WASH studies[37 40 41] which reported WASH plus nutrition versus nutrition and WASH plus nutrition versus WASH on WAZ. Using these three studies, we found MD=0.00; 95% CI −0.11 to 0.12 for WASH plus nutrition versus nutrition and MD=0.16; 95% CI 0.11 to 0.22 for WASH plus nutrition versus WASH interventions.

Weight-for-height

Data on WHZ were available in four non-RCTs and seven RCTs, and no evidence of an effect was detected from both non-RCTs (MD=−0.10; 95% CI −0.19 to 0.00) and RCTs (MD=−0.01; 95% CI −0.05 to 0.03) (online supplementary figure 3). There was no evidence of heterogeneity in both non-RCTs and RCTs (I^2=0%). The pooled estimate of non-RCT studies and RCTs together did not show a statistically significant effect on WHZ (MD=−0.03; 95% CI −0.06 to 0.01). Although the heterogeneity was minimal (I^2=3%), a borderline effect was detected for WHZ from combined WASH with nutrition interventions (MD=0.04; 95% CI 0.00 to 0.09, p=0.04) (plot not shown). Using three studies we found MD=0.01; 95% CI −0.07 to 0.09 for WASH plus nutrition versus nutrition and MD=0.10; 95% CI 0.05 to 0.16 for WASH plus nutrition versus WASH interventions.

Publication bias and sensitivity analysis

The funnel plot shows there was no evidence of publication bias for all studies. The plot was symmetrical (online supplementary figure 4); Egger's test provided a p value of 0.976 for bias. There was also no evidence of publication bias detected from separate plots for RCTs and non-RCTs (online supplementary figure 5); Egger's test gave p values of 0.873 for non-RCT and 0.365 for RCTs, respectively. Omitting each study did not influence the pooled estimate, and results from fixed and random effects models were not different (data not shown).

Meta-regression

The coefficients of regressed effect measures on the moderators (general domain, risk of bias and items that measure risk of bias) are given in table 3. The effect measure was increased with baseline outcome measurements between intervention and control groups (p=0.007)

Table 2 Subgroup meta-analyses for the effect of WASH interventions alone on child growth outcomes stratified by characteristics of the included studies

	HAZ			WAZ			WHZ		
Potential effect modifier	**No. of studies**	**I^2 (%), p value**	**Pooled MD (95% CI)**	**No. of studies**	**I^2 (%), p value**	**Pooled MD (95% CI)**	**No. of studies**	**I^2 (%), p value**	**Pooled MD (95% CI)**
Age*									
0–2 years	4	74 to 0.01	**0.07 (0.01 to 0.13)**	3	85 to 0.003	0.00 (−0.15 to 0.16)	0	n/a	n/a
<5 years	4	72 to 0.01	0.05 (−0.00 to 0.11)	3	74 to 0.02	−0.00 (−0.10 to 0.09)	0	n/a	n/a
Setting									
Pre-urban and rural	1	n/a	0.11 (−0.19 to 0.41)	1	n/a	−0.01 (−0.23 to 0.21)	1	n/a	−0.11 (−0.30 to 0.08)
Urban slum	1	n/a	−0.13 (−0.54 to 0.28)	1	n/a		1	n/a	−0.11 (−0.53 to 0.31)
Rural	14	74, <0.001	0.02 (−0.04 to 0.09)	13	38 to 0.08	−0.02 (−0.06 to 0.01)	9	0 to 0.62	−0.02 (−0.06 to 0.02)
Length of intervention									
6–12 months	5	22 to 0.27	−0.04 (−0.12 to 0.03)	5	0 to 0.95	−0.05 (−0.11 to −0.00)	2	0 to 1.00	−0.11 (−0.29 to 0.07)
18–60 months	11	76, <0.001	**0.04 (0.01 to 0.08)**	10	48 to 0.04	−0.01 (−0.06 to 0.04)	9	0 to 0.62	−0.02 (−0.06 to 0.02)
Geographical region									
Sub-Saharan Africa	6	80, <0.001	**0.06 (0.01 to 0.10)**	5	58 to 0.05	−0.02 (−0.06 to 0.03)	3	0 to 0.73	−0.05 (−0.11 to 0.01)
Southern Asia	7	73 to 0.001	0.01 (−0.13 to 0.15)	7	24 to 0.24	**−0.04 (−0.10 to −0.01)**	5	0 to 0.93	−0.02 (−0.09 to 0.05)
Southeast Asia	1	n/a	0.01 (−0.09 to 0.11)	1	n/a	0.03 (−0.06 to 0.12)	1	n/a	0.06 (−0.04 to 0.16)
South America	2	0 to 0.94	−0.04 (−0.16 to 0.09)	2	0 to 0.87	−0.04 (−0.13 to 0.06)	2	50 to 0.16	−0.04 (−0.18 to 0.11)
Type of intervention									
Behaviour change education	5	79 to 0.001	0.13 (−0.03 to 0.30)	5	38 to 0.17	0.05 (−0.03 to 0.13)	4	0 to 0.60	0.03 (−0.04 to 0.11)
More direct intervention	3	35 to 0.21	−0.09 (−0.25 to 0.07)	3	0 to 0.94	−0.05 (−0.12 to 0.03	1	n/a	−0.11 (−0.30 to 0.08)
Behaviour change+direct intervention	8	64 to 0.007	0.01 (−0.06 to 0.08)	7	0 to 0.83	**−0.05 (−0.09 to −0.02)**	6	0 to 0.84	−0.04 (−0.08 to 0.00)

Significant findings are in bold font.
*Subgroup analysis included RCTs only.
HAZ, height-for-age z-score; MD, mean difference; n/a, not applicable; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score.

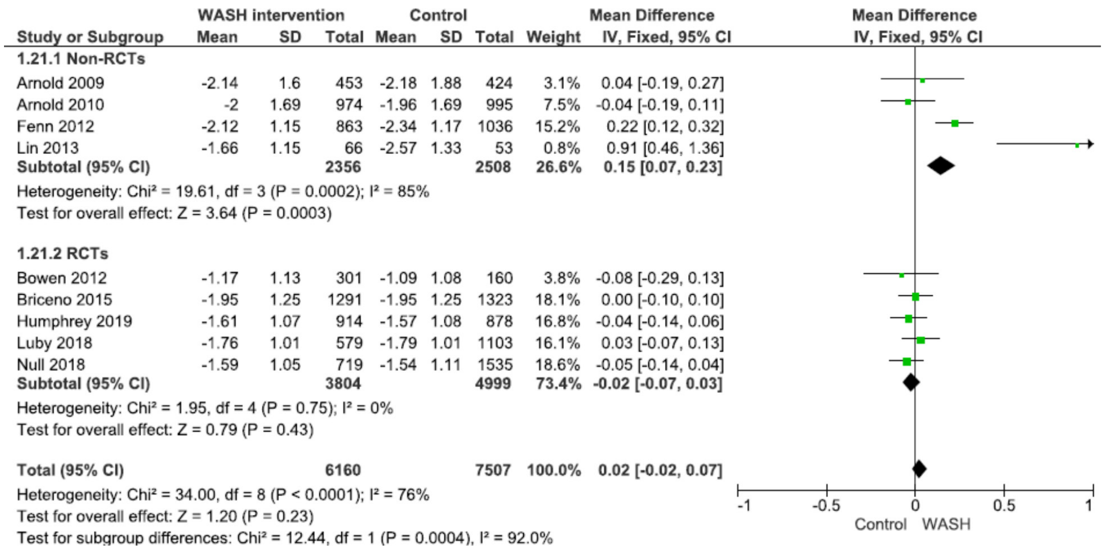

Figure 3 Forest plot of combined water, sanitation and hygiene (WASH) components (two or three) versus control for height-for-age z-score. RCT, randomised controlled trial.

and was inversely associated with baseline characteristics of study participants in both arms (p=0.009).

DISCUSSION

We reviewed evidence of the effect of WASH interventions alone, separately, and when combined with nutrition on child growth. Our review focused on three child growth measures: HAZ, WAZ and WHZ. In this review, WASH interventions alone from non-RCTs were found to improve HAZ compared with RCTs. The overall pooled estimate from both non-RCTs and RCTs together indicated no effect of WASH interventions alone on HAZ. The findings of the current study do not support the previous research by Gera *et al* which showed that WASH interventions improved HAZ by 22%.[12] The meta-analysis from five RCTs conducted by Dangour and colleagues showed a borderline effect on HAZ.[11] Another meta-analysis by Freeman *et al* showed a borderline effect of WASH interventions after pooling non-RCTs and RCTs together.[17] RCT studies failed to show evidence of an effect on HAZ. A possible explanation for this might be that population level WASH interventions using a community approach may have an increased positive effect compared with household level interventions. In addition, long-term exposure to high quality hygiene and sanitation may be required to improve child linear growth. There is a lesson to be learned from three RCTs that showed WASH interventions improved diarrhoea in Bangladesh[40] but not in Kenya[41] and Zimbabwe.[37] However, one plausible explanation is that there may have been unmeasured confounding variables in the non-RCT studies.

Regardless of the duration of interventions and age range of study subjects, the value of the effect estimate in the current study suggests a weak link may exist between WASH interventions alone and HAZ. There are several plausible reasons for weak evidence of an effect. First, some studies in the current review were studies of WASH intervention programme evaluations. These evaluations assessed the capability of specific interventions under low uptake, low adherence and with a high risk of contamination that may have contributed to underestimating the true effect of WASH interventions. Second, the analysis of reviews was based on a combination of individual and/or combined WASH components which may have contributed

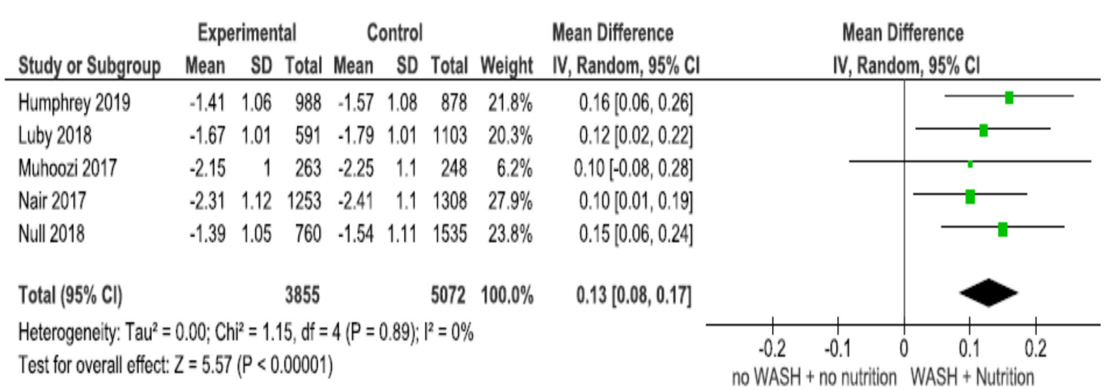

Figure 4 Forest plot of water, sanitation and hygiene (WASH)+nutrition versus no-WASH+no-nutrition for height-for-age z-score.

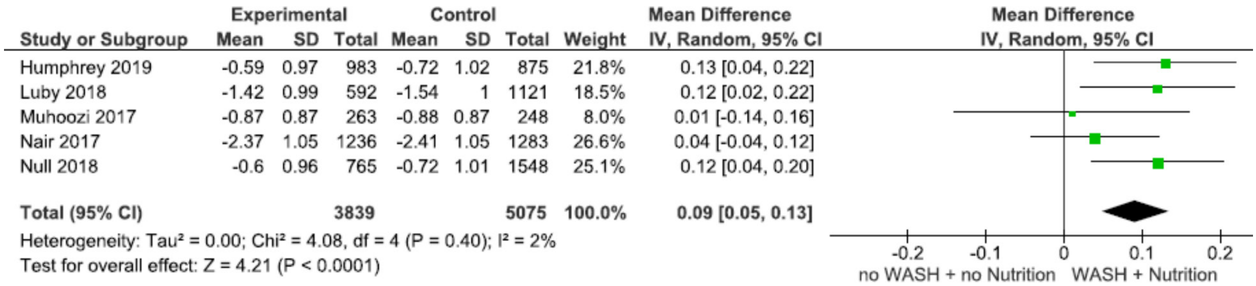

Figure 5 Forest plot of water, sanitation and hygiene (WASH)+nutrition versus no-WASH+no nutrition for weight-for-age z-score.

to discrepancies in effect size. The current review found a positive effect of WASH interventions from non-RCTs on linear growth when at least two components of WASH were provided together. These findings further support the idea of previous studies[44 45] that integrated components of WASH may be more effective compared with single interventions. The age of the child receiving the interventions is also important, as shown in subgroup analyses.

Children <2 years of age were more likely to respond to WASH interventions compared with children <5 years for linear growth. This result matches that observed in a previous review.[11] The current review supports previous studies which suggested that interventions should focus on the first 1000 days of a child's life.[46–48] The first 1000 days of life are characterised by rapid growth, high nutrition requirements, greater susceptibility to infections, and full dependence on others for care, nutrition and high social interaction.[46] Duration of the interventions also appears to be important in the current study. WASH interventions that were delivered over a duration of 18–60 months showed improved HAZ compared with interventions delivered over 6–12 months. This result is a new and novel finding that has not been described in previous reviews. One explanation is that WASH is often interlaced with other complex interventions that require behavioural change over an extended period to see any positive effect. Also, linear growth failure typically arises from chronic undernutrition which requires long-term adherence to interventions to observe positive change.[49]

This review also found, for the first time, a significant positive effect of combined WASH with nutrition interventions on child's HAZ. The observed improvement in linear growth could be attributed to the synergistic effect of combined WASH with nutrition interventions. This finding has an important implication for developing an integrated intervention approach for WASH and nutrition sectors in order to tackle child linear growth failure. A previous study suggested 90% coverage of nutrition interventions would only decrease stunting by 20%,[13] while interventions such as WASH shares a large portion of the remaining burden.[9] There were lessons we can learn from the WASH-Benefit studies[40 41] and Sanitation Hygiene Infant Nutrition Efficacy (SHINE) trail[37] in which child feeding interventions slightly (12% points) increased child linear growth. Overall,

Table 3 Results of meta-regression analyses of mean difference in child growth on quality scores items of the included studies

Categories	Items in quality score (moderators)	Regression coefficient (95% CI)	SE	P value
Overall quality	Intercept	0.01 (−0.88 to 0.91)	0.466	0.975
	General domain vs total score	0.01 (−0.02 to 0.04)	0.017	0.571
	Risk of bias vs total score	−0.01 (−0.02 to 0.00)	0.006	0.154
	Total score	Reference	–	–
Risk of bias	Intercept	0.68 (−0.08 to 1.43)	0.384	0.078
	Sequence generation	−0.01 (−0.05 to 0.03)	0.020	0.502
	Allocation concealment	0.03 (−0.02 to 0.08)	0.024	0.229
	Was baseline outcome similar?	0.06 (0.02 to 0.10)	0.021	0.007
	Were baseline characteristics similar?	−0.13 (−0.23 to −0.03)	0.051	0.009
	Incomplete outcome data addressed	0.03 (−0.04 to 0.09)	0.033	0.412
	Blinding of participants	0.03 (−0.03 to 0.08)	0.029	0.350
	Blinding of outcome assessment	0.01 (−0.04 to 0.06)	0.024	0.756
	Was there selective reporting bias?	−0.02 (−0.06 to 0.03)	0.024	0.494
	Protection against contamination	0.02 (−0.03 to 0.06)	0.023	0.474
	Adequately adjusted for confounders?	−0.03 (−0.10 to 0.04)	0.0345	0.345
	Total score of risk of bias	Reference	–	–

there appears to be evidence to indicate that the component of intervention, either WASH alone or combined with nutrition, age of child, and duration of interventions, have an impact on child growth.

The current review did not detect evidence of benefit from WASH interventions alone for weight growth (WAZ). The present findings seem to be consistent with other research which found no evidence of an effect from WASH interventions alone.[11] However, the findings of the current review do not support previous reviews which found WASH interventions alone improved WAZ of children.[12 17] The current study results must be interpreted with caution because the Gera *et al* study found a small positive effect on WAZ from water supply and water treatment interventions only, whereas the Freeman *et al* review was based on sanitation only. The results of the current review from subgroup analysis by age and exposure duration to interventions did not show a significant benefit from WASH interventions alone for WAZ. However, the combined interventions of WASH with nutrition was found to improve WAZ. In reviewing the literature, there appears to be no published evidence on the effect of combined WASH with nutrition interventions on WAZ, making this a new finding in the research literature. Being a new finding, further studies and reviews will be important to undertake to add further support to these findings. In the current review, we found no evidence of an effect on WHZ from WASH interventions alone and a borderline effect from combined WASH interventions with nutrition. The findings are consistent with previous reviews that detected no evidence of an effect of WASH interventions on WHZ.[11 12 17] Subgroup analysis based on age and interventions duration also did not change the value of WHZ in the current review.

Strengths and limitations

This study reviewed evidence from studies that were conducted in low and middle-income countries following the guidelines of PRISMA. We explored data from both RCTs and non-randomised studies. Our analyses are grouped into key indicators which show a clear summary of intervention outcomes. Sources of heterogeneity were assessed using subgroup analysis and meta-regressions based on the known factors. Most of the methodological quality of the included studies was deemed very low, low and medium, that is, none of the included studies had low risk of bias. We included few studies in the meta-analysis of individual WASH components alone and combined with nutrition due to the lack of consistency in reporting outcomes and summary statistics. Therefore, true heterogeneity between studies and correct publication bias may not have been detected. As few studies were included in the meta-analysis, this study could not confirm that the effect of WASH plus nutrition versus nutrition or WASH on child growth may be due to nutrition only.

CONCLUSIONS

The present review found that HAZ was more responsive to WASH interventions alone that were delivered over 18–60 months and among children <2 years of age. HAZ could be improved through combined WASH with nutrition interventions. Improvement in WAZ was indicated in a group with combined WASH with nutrition interventions. Although no evidence of an effect was found from WASH interventions alone on WHZ, we found a borderline effect when combined with nutrition. Well-designed epidemiological studies are recommended that examine the minimum length of intervention necessary to be effective and the role of behavioural aspects including social norms in the implementation of WASH interventions. WASH and nutrition interventions should be considered together when designing strategies to tackle CGF with a particular focus on the first 1000 days of a child's life.

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Contributors TB conceived the idea, searched and screened all relevant articles, extracted the data, performed analysis, assessed quality and drafted the manuscript. PR and BR checked the screened and excluded studies by the primary author and edited the manuscript.

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Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

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