H2Open Journal

IWA PUBLISHING

H2Open Journal Vol 5 No 4, 583 doi: 10.2166/h2oj.2022.137

Interventions to address unsafe child feces disposal practices in the Asia-Pacific region: a systematic review

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ABSTRACT

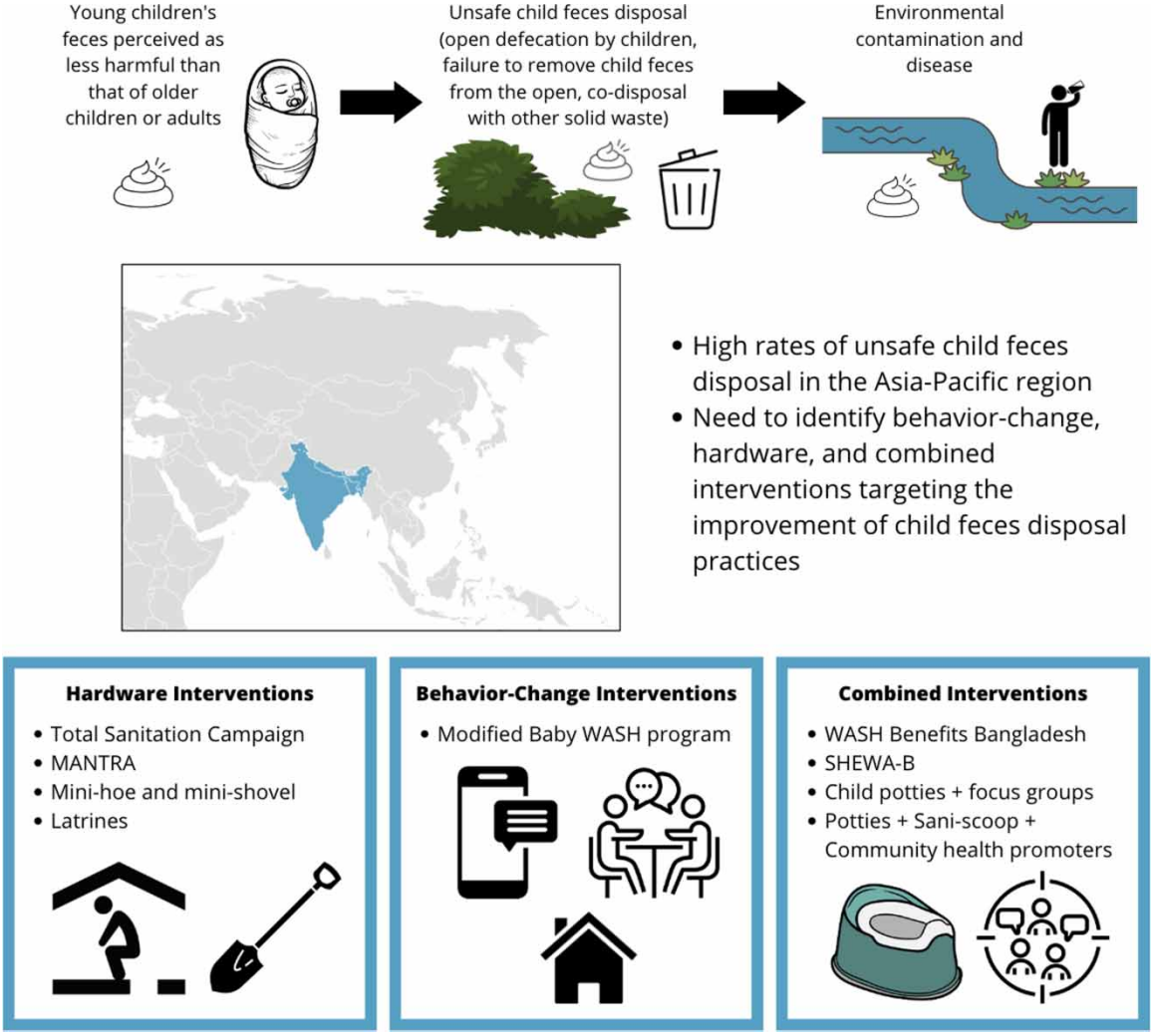
Despite clear evidence of the adverse health impacts of unsafe child feces disposal (CFD), there is little evidence of the effectiveness of interventions targeting the improvement of unsafe CFD practices in the Asia-Pacific region. A systematic review of the literature was conducted to identify and evaluate the quality of both behavior change and hardware interventions targeting the improvement of CFD practices in this region. A total of 695 articles were screened, and 15 studies were included. The combined hardware and behavior change interventions reported the highest rates of safe CFD (SCFD) post-intervention; however, these interventions were of lower quality. Four interventions focused specifically on improving SCFD practices, while the remaining seven studies evaluated the impacts of large-scale interventions, such as India's MANTRA and Total Sanitation Campaign programs, on unsafe CFD practices. Large-scale programs and hardware interventions are important for providing communities with the infrastructure necessary to improve unsafe CFD practices, but such interventions may be improved by the addition of a behavioral change component. With little evidence available on the effectiveness of behavioral interventions on reducing unsafe CFD in the Asia-Pacific region, future work should focus on how behavior change models combined with hardware interventions impact unsafe CFD.

Key words: Asia-Pacific, behavior change interventions, child feces disposal, hardware interventions, sanitation interventions, water sanitation and hygiene (WASH)

HIGHLIGHTS

- The Asia-Pacific region has high rates of unsafe child feces disposal (CFD).
- There is little evidence on the effectiveness of sanitation interventions targeting the improvement of unsafe CFD practices.
- Hardware interventions may be improved by the addition of a behavioral change component.
- Future work should focus on how behavior change models combined with hardware interventions address unsafe CFD practices.

GRAPHICAL ABSTRACT



INTRODUCTION

In 2017, an estimated 2 billion people lacked access to basic sanitation services, with 673 million practicing open defecation (UNICEF & WHO 2019). Each year, the diarrheal disease causes over 800,000 deaths due to a lack of access to water and sanitation, of which nearly 300,000 are children (Prüss-Ustün *et al.* 2019). Eliminating open defecation is one of the Sustainable Development Goals (SDGs) and has been a major water, sanitation, and hygiene (WASH) sector priority, particularly in the Asia-Pacific region where rates of unsafe feces disposal can exceed 50% (UNICEF & WHO 2019). Most interventions to reduce open defecation have focused primarily on adults, even though the safe disposal of child feces is just as essential from a public health standpoint (Chakma *et al.* 2008; Majorin *et al.* 2014; Rand *et al.* 2015). The United Nations Children's Fund and World Health Organization's Joint Monitoring Programme (JMP) defines safe child feces disposal (SCFD) as a child defecating directly into an improved latrine or a caregiver depositing or rinsing child stools into an improved latrine (UNICEF & WHO 2019). Unsafe CFD (unsafe CFD), therefore, involves open defecation by children, failure to remove child feces from the open, or co-disposal of child feces with other solid wastes if that solid waste is not disposed of in a sanitary manner (Majorin *et al.* 2019; UNICEF & WHO 2019).

The Asia-Pacific region has particularly high rates of unsafe CFD; in India, for example, the JMP estimates that 60% of child feces are disposed of unsafely (UNICEF & WHO 2019). This percentage, however, is estimated based on latrine access rather than actual CFD practices, so the true prevalence of unsafe CFD is likely underestimated. Majorin *et al.* (2014) and Preeti *et al.* (2016) found rates of unsafe CFD to be 81 and 73% in India, respectively – substantially higher than the JMP estimate. Households practicing unsafe CFD show a higher

prevalence of childhood diarrheal disease compared to those practicing safe disposal (Bawankule *et al.* 2017; Islam *et al.* 2020). Unsafe CFD is associated with environmental enteropathy in children, a disease of chronic intestinal inflammation, in addition to impaired growth and development (George *et al.* 2016).

Development of effective interventions to address unsafe CFD requires an understanding of the drivers behind this behavior. One of the most significant determinants of CFD practices is the use of a toilet by adults in the household (WSP 2015). Bauza *et al.* (2019) found that CFD was more likely to be unsafe if female adults in the household did not defecate into a toilet, and Islam *et al.* (2018) found unsafe CFD to be more common in rural areas, which may be due to the higher prevalence of open defecation by adults in these areas (UNICEF & WHO 2019). A study conducted by Beardsley *et al.* (2021) evaluated factors associated with unsafe CFD in India and found that the poorest wealth quintile was significantly more likely to practice unsafe CFD, as well as households in which females did not attend primary school. Preeti *et al.* (2016) and Ayele *et al.* (2018) found parents' educational attainment to be significantly associated with feces disposal practices, with less educated households more likely to practice unsafe CFD. Lower-income households' association with unsafe CFD is potentially due to poor access to child defecation materials or the lack of income to purchase nappies or latrines that children can use (Miller-Petrie *et al.* 2016; Preeti *et al.* 2016; Ayele *et al.* 2018).

In addition to household income and educational attainment, access to a sanitation facility, whether improved or unimproved, was also significantly associated with SCFD (Beardsley *et al.* 2021). The presence of water at the handwashing site and child age have also shown associations with SCFD (Azage & Haile 2015; Islam *et al.* 2018; Bauza *et al.* 2019). The prevalence of unsafe CFD was found to be higher when there was no water present for handwashing, as well as when the children in the household were younger (Azage & Haile 2015; Islam *et al.* 2018; Bauza *et al.* 2019). In terms of child age, Azage & Haile (2015) and Islam *et al.* (2018) reported that the feces of children younger than 18 months and younger than 12 months of age, respectively, were more likely to be disposed of unsafely compared to that of older children. This may be due to the perception that younger children's feces are less harmful or are less likely to cause sickness than those of older children or adults (Brown *et al.* 2013; Ayele *et al.* 2018).

Though clear evidence of the adverse health impacts of unsafe CFD continues to arise, there is little evidence on the effectiveness of interventions targeting the improvement of CFD practices in the Asia-Pacific region (Rand *et al.* 2015). Morita *et al.* (2016) and Majorin *et al.* (2019) conducted systematic reviews of interventions to improve CFD practices to prevent the disease, but both had a global focus and found inconclusive evidence on the effectiveness of these interventions. Morita *et al.* (2016) and Majorin *et al.* (2019) both identified only one intervention whose sole focus was to improve CFD behaviors (Yeager *et al.* 2002). This sole study did not result in a significant reduction of unsafe CFD behaviors. All other studies assessed by Morita *et al.* (2016) and Majorin *et al.* (2019) evaluated packaged WASH interventions in which CFD was only a small component, suggesting that the improvement of CFD behaviors has not been a research priority. Majorin *et al.* (2019) suggested that children should be encouraged to use latrines and that child feces should be disposed of into latrines; however, the evidence reviewed was of low certainty, and the authors were unsure about the interventions' true effects.

The objectives of the present study are (1) to identify both behavior change and hardware interventions targeting the improvement of CFD practices in the Asia-Pacific region, (2) to assess the strengths and weaknesses of the identified behavior change and hardware interventions, and (3) to compare the effectiveness of behavior change versus hardware interventions at improving CFD practices in order to provide recommendations for promoting SCFD.

METHODS

A systematic review of published literature was conducted using PubMed, Embase, and the Global Health database within EBSCO. Search terms were related to children, feces disposal, and Southern and Eastern Asian countries. Medical subject heading (MeSH) terms in PubMed and Emtree terms in Embase were used to facilitate searches and identify the full body of literature. Terms for feces disposal were limited to titles and abstracts by utilizing the [tiab] search feature in PubMed and its equivalents in Embase and the Global Health database. Search terms used in this our study are presented in the Supplementary Materials. Initial searches including the Southern/Eastern Asia terms yielded few results; searches were modified to exclude these terms, and articles were manually screened to include only studies that took place in this geographic region.

Database searches were limited to articles published in English in 2011 or later, and the final search was conducted on May 31, 2021. Only studies conducted within this 10-year period were included to reflect new evidence of interventions to improve CFD practices. All studies were uploaded to Covidence, a systematic review production online tool, and duplicate studies were removed. Two reviewers screened the remaining studies by title and abstract for relevance, with a third reviewer acting as a tie-breaker. The final selection of studies occurred after full-text review.

Studies selected for inclusion must have included interventions where changes in CFD practices were measured as an outcome. These included interventions with a specific CFD component as well as hardware interventions that would enable CFD in latrines and toilets. Studies on interventions that only measured open defecation by adults and review articles were excluded. Results were then synthesized by study characteristics such as age group, sample size, intervention time frame, intervention description (hardware or behavioral, general summary), and behavioral outcomes and findings. Quality assessment was performed by two reviewers and involved describing the level of evidence (Ackley *et al.* 2008; Brownson *et al.* 2009; Manga *et al.* 2021) and risk of bias (Sterne *et al.* 2016; Higgins *et al.* 2022) that were then used to rate overall certainty.

The level of evidence was assigned to studies based on the methodological quality of their design and applicability. Levels were ranked as A, B, C, or D, with A being the highest level of evidence. Because systematic reviews were excluded from this review, Level A was reserved for randomized controlled trials (RCTs) (Ackley *et al.* 2008). Other peer-reviewed research such as cohort and cross-sectional studies were rated Level B. Level C included government reports, and Level D was assigned to pilot studies and formative research (Brownson *et al.* 2009).

The risk of bias was evaluated using the risk-of-bias tool (RoB 2) for RCTs (Higgins *et al.* 2022) and the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool for other study types (Sterne *et al.* 2016). RoB 2 analysis involved the evaluation of bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in outcome measurements, and bias in the selection of the reported result (Higgins *et al.* 2022). Domains in ROBINS-I that are not included in RoB 2 include bias due to confounding, selection bias, and bias in the classification of interventions (Sterne *et al.* 2016).

Overall certainty ratings imply confidence that the true effect lies close to the estimated effect determined in the study. Studies at Level A were initially given a high certainty, studies at level B were rated intermediate, and studies at Level D were initially rated as low. Overall certainty was then either increased or decreased based on the risk of bias estimates. Based on the information obtained through this review, recommendations for future programs and interventions were provided.

RESULTS

Study selection

A total of 695 articles were retrieved from PubMed, Embase, and the Global Health database, after which 386 duplicates were removed, leaving 309 studies for screening (Figure 1). Among these studies, 269 were found to be irrelevant after the title and abstract screening. Full texts of the remaining 40 studies were then reviewed based on inclusion criteria, and an additional four studies were identified via the reference checking 'snowball' method. Fifteen studies were found to be eligible for inclusion. The selected studies represented three Asian-Pacific countries (Figure 2).

The 29 studies excluded after full-text screening either did not include interventions where changes in CFD practices were measured as an outcome (i.e., 'Wrong study design'), were conducted outside of the Asia-Pacific region, were outside of the 10-year time frame, or were duplicates of another article.

For example, Bawankule *et al.* (2017) assessed associations of unsafe CFD with childhood diarrhea in India but did not describe an intervention to address those factors, and this study was therefore excluded. Majorin *et al.* (2019) and Igaki *et al.* (2021) both conducted systematic reviews of interventions that included improving CFD practices among other factors, but reviews were not an included reference type, so these studies were excluded.

Gimaiyo *et al.* (2019) and Ellis *et al.* (2020) assessed CFD practices in Kenya, which is not in the Asia-Pacific region. Studies conducted by Stanton & Clemens (1987) and Baltazar & Solon (1989) were also excluded as they were outside of the 10-year time constraint.

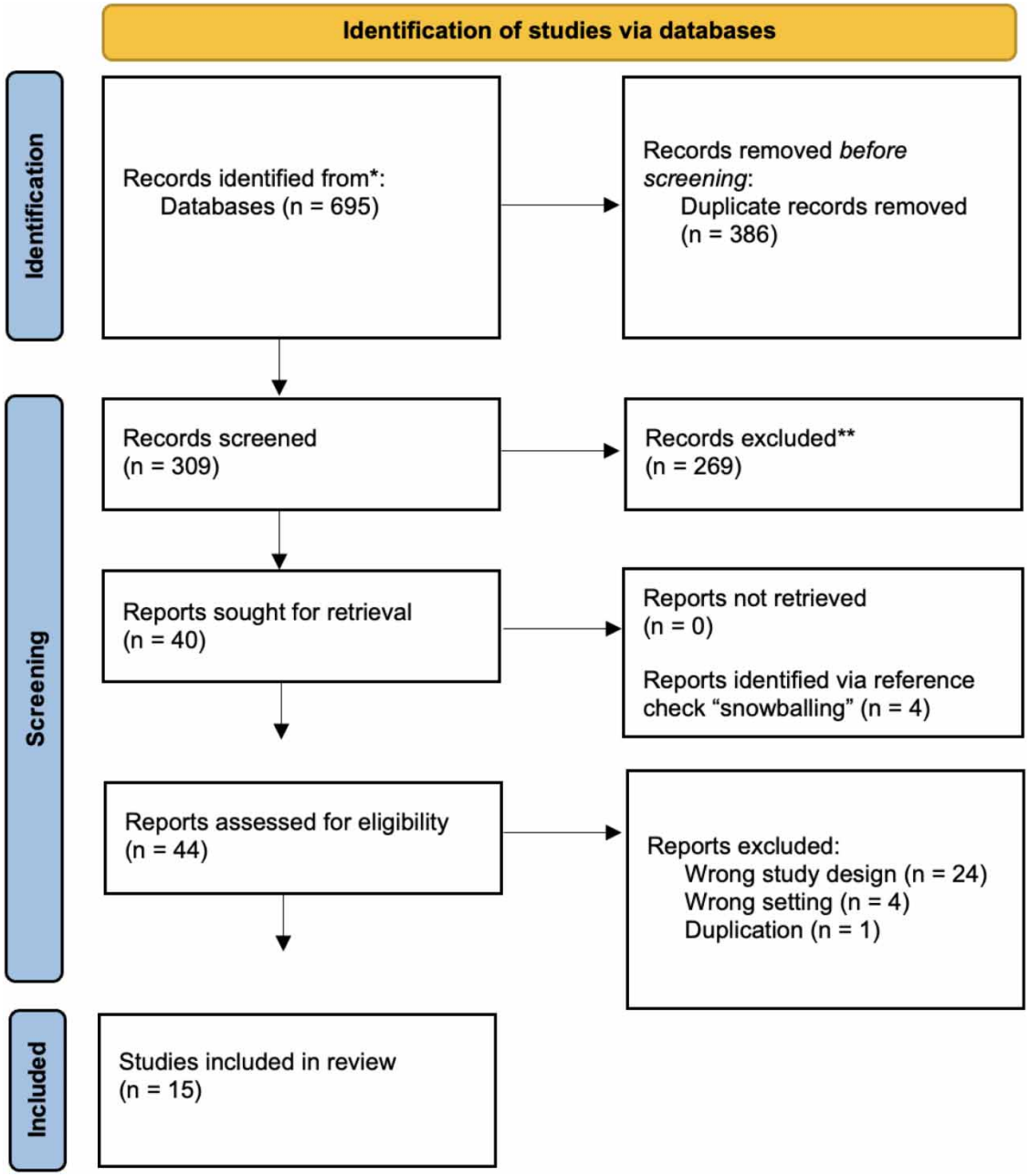


Figure 1 | Process for selecting studies in this review of CFD practices in Asian-Pacific countries.

Summary of findings and quality assessment

The 15 studies selected for inclusion were evaluated for level of evidence, risk of bias, and overall quality. A more detailed summary of the study findings is shown in Table 1. Quality assessment results are shown in Table 2.

India's Total Sanitation Campaign consisted of government subsidies to improve sanitation access for those below the poverty line. MANTRA was another program in rural Odisha, India delivered by a non-governmental organization that aimed to increase latrine ownership by encouraging all households in a village to build their own latrines, with piped water provided through the program. These two interventions required participants to construct their own pour-flush latrines for household use. While these hardware interventions led to increased access to improved sanitation, high rates of unsafe CFD still persisted (Majorin *et al.* 2014; Bauza *et al.* 2019; Reese *et al.* 2019). Only 35% of villages reported SCFD following the MANTRA program (Bauza *et al.* 2019; Reese *et al.* 2019), and less than 30% reported SCFD following the Total Sanitation Campaign (Majorin *et al.* 2014; Patil *et al.* 2014; Freeman *et al.* 2016). Bauza *et al.* (2019) and Reese *et al.* (2019) are included together

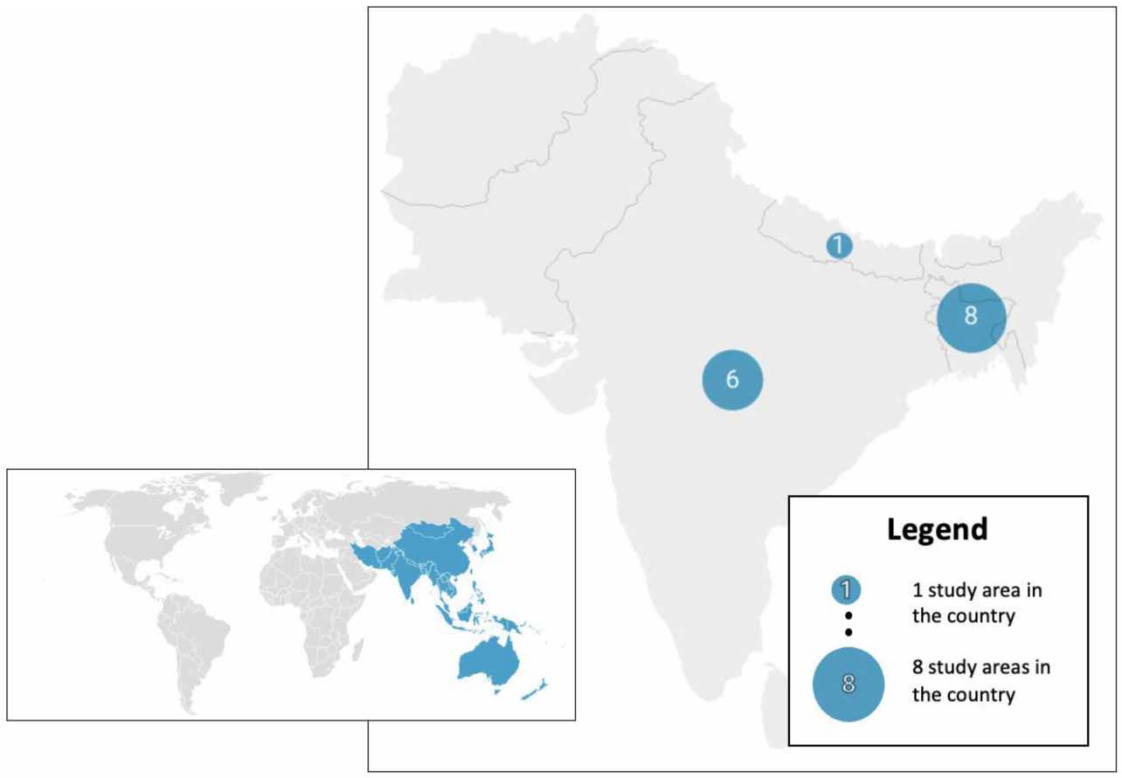


Figure 2 | Geographic distribution of studied included in review of CFD practices in Asian-Pacific countries. Six studies (40%) were conducted in India, eight studies (53%) were conducted in Bangladesh, and one study (7%) was conducted in Nepal.

as one study reported in two papers, as Bauza *et al.* conducted a deeper dive into the CFD aspects of the same program. These study findings suggest that although improved sanitation is a necessary component of SCFD, its sole implementation does not guarantee SCFD as other components are equally important, particularly behavior change interventions directed toward caregivers of young children.

The WASH Benefits Bangladesh trial and Sanitation, Hygiene Education and Water Supply in Bangladesh program (SHEWA-B) were two other large-scale interventions implemented in rural Bangladesh. In contrast to the Total Sanitation Campaign and the MANTRA program, WASH Benefits and SHEWA-B also included behavioral components. WASH Benefits used community promoters to encourage mothers to teach their children to use potties, to safely dispose of feces in latrines, and to regularly remove human and animal feces from the compound. SHEWA-B also involved home visits by community promoters, in addition to community meetings and social mobilization activities. WASH Benefits showed decreases in the presence of visible feces around the household (Luby *et al.* 2018; Parvez *et al.* 2018). Observed safe disposal of feces from child potties was moderate (Parvez *et al.* 2018). Neither WASH Benefits nor SHEWA-B showed statistically significant improvements in CFD behaviors or child defecation in potties or latrines (Huda *et al.* 2012; Parvez *et al.* 2018).

In addition to large-scale improved sanitation programs, small-scale sanitation hardware was a component of some interventions. These included the provisioning of tools to improve CFD practices, such as mini-hoes, sani-scoops, and child potties (Ashraf *et al.* 2012; Sultana *et al.* 2013; Hussain *et al.* 2017). Ashraf *et al.* (2012) and Hussain *et al.* (2017) conducted small-scale hardware interventions that also included a behavioral component. Ashraf *et al.* (2012) utilized Community Health Promoters, who visited households three times during the study duration and used cue cards, images, and text messages to encourage sanitation use. Hussain *et al.* (2017) conducted group discussions and individual interviews throughout a 30-day period to gather data on potty likes and dislikes, feces disposal practices, barriers to use, and recommendations for improvement. Ashraf *et al.* (2012) reported an increase in SCFD from 25% at baseline to 73% at 3 months post-intervention, and Hussain *et al.* (2017) reported an increase from 4 to 85%. These two combined hardware and behavior change interventions reported the greatest increases in SCFD post-intervention of all studies included in the review.

Table 1 | Summary of locations, age groups, sample sizes, durations, intervention types, and their outcome measures and overall findings of studies included in review of interventions targeting CFD practices in Asian-Pacific countries

Authors	Location	Age group/inclusion criteria	Sample size	Duration of study	Intervention type: intervention description	Data collection methods	Outcome measures	Impacts on CFD practices
Luby *et al.* (2018)	Rural Bangladesh	*Intervention group*: Households that had participated in the WASH Benefits Bangladesh trial with pregnant women assigned to the following groups: chlorinated drinking water (water); upgraded sanitation (sanitation); promotion of handwashing with soap (handwashing); combined water, sanitation, and handwashing; counselling on appropriate child nutrition (nutrition); combined water, sanitation, handwashing, and nutrition. *Control group*: data collection only.	5,551 pregnant women in intervention groups in the WASH Benefits trial; 1,382 women in the control group.	Evaluated WASH Benefits Bangladesh outcomes at 1- and 2-years post-intervention (intervention delivered over 15 months).	*Hardware and Behavioral*: WASH Benefits Bangladesh was a cluster-randomized trial that enrolled pregnant women and evaluated outcomes at 1- and 2-years follow-up. All households in groups with sanitation component received latrine installation or repairment, a sani-scoop for removing feces from the compound, and households with children <3 received child potties. Promoters encouraged mothers to teach their children to use the potties, to safely dispose of feces in latrines, and to regularly remove animal and human feces from the compound.	Caregiver-reported data, and the presence of feces on latrine slab or floor.	Comparison to control and baseline % of latrines with functional water seals and the presence of visible feces on latrine slab or floor.	*Sanitation groups*: 48–56% of households had visible feces on floor at baseline compared to 11–14% at 1 year and 14–18% at 2 years. 26–30% had latrine water seals at baseline compared to 95 and 97% at 1 and 2 years. *Control group*: 52% of households had visible feces on floor at baseline compared to 40% at 1 year and 44% at 2 years. 31% had functional latrine water seals at baseline compared to 29 and 31% at 1 and 2 years.
Parvez *et al.* (2018)	Rural Bangladesh	*Intervention group*: Households that had participated in the WASH Benefits Bangladesh trial with pregnant women assigned to the following groups: chlorinated drinking water (water); upgraded sanitation (sanitation); promotion of handwashing with soap (handwashing); combined water, sanitation, and handwashing; counselling on appropriate child nutrition (nutrition); combined water, sanitation, handwashing, and nutrition. *Control group*: data collection only.	5,551 pregnant women in intervention groups; 1,382 women in the control group.	Fidelity assessments over 20 months from November 2012 to October 2014.	*Hardware and Behavioral*: WASH Benefits Bangladesh was a cluster-randomized trial that enrolled pregnant women and evaluated outcomes at 1- and 2-year follow-up. All households in groups with sanitation component received latrine installation or repairment, a sani-scoop for removing feces from the compound, and households with children <3 received child potties. Promoters encouraged mothers to teach their children to use the potties, to safely dispose of feces in latrines, and to regularly remove animal and human feces from the compound.	Implementation fidelity and structured observations. Monthly spot-checks and surveys for technology and behavioral uptake (feces presence in the courtyard as an indicator of sani-scoop use and safe feces disposal).	Observed hygienic latrine, feces presence in the courtyard as an indicator of sani-scoop use and safe feces disposal.	*Sanitation groups*: 24–38% of households had stool visible on floor ($p < 0.01$ compared to control). Observed safe disposal of human feces using sani-scoop was moderate (30–38% of events, $p > 0.05$). Observed child defecation in potty or latrine (37–54% of events, $0.28 < p < 0.81$) *Control group*: 62% had stool visible on floor. Observed safe disposal of human feces (16% of events). Observed child defecation in potty or latrine (32% of events).
Rahman *et al.* (2018)	Bangladesh	Those enrolled in the WASH Benefits Bangladesh trial	4,169 enrolled households	6 months	*Hardware and Behavioral*: Combined water quality, sanitation, handwashing, and child nutrition interventions.	Monthly household surveys and spot-checks	Intervention fidelity	CFD into latrine met target benchmark (65% of households) at each monthly check.

(*Continued.*)

Table 1 | Continued

Authors	Location	Age group/inclusion criteria	Sample size	Duration of study	Intervention type: intervention description	Data collection methods	Outcome measures	Impacts on CFD practices
					Households received free enabling technologies integrated with behavior change promotion.			
Huda *et al.* (2012)	Rural Bangladesh	*Intervention group*: Households enrolled in the Sanitation, Hygiene Education and Water Supply in the Bangladesh program (SHEWA-B). *Control*: data collection only.	SHEWA-B targeted 20 million rural people. Huda *et al.* selected 1,000 households for structured observations.	24 months	*Hardware and Behavioral*: SHEWA-B targeted improvements in hygiene behaviors while ensuring adequate sanitation and safe water supply. The program engaged local residents to design their own community action plans, including targets for improvements in latrine coverage and usage; access to and use of arsenic-free water; and improved hygiene practices, especially handwashing with soap. Community promoters visited households, facilitated courtyard meetings, and organized social mobilization activities.	Structured observation of CFD of all persons in household (monthly observations for 24 months).	Observed CFD	*Intervention group*: At baseline, 9.3% of households practiced SCFD, compared to 16% at follow-up ($p = 0.84$ compared to control). *Control group*: At baseline, 9% of households practiced SCFD, compared to 15% at follow-up.
Sultana *et al.* (2013)	Three villages of Faridpur district in Bangladesh	Households with children <3 years for intervention, and women were between 20 and 35 years.	44 women/mothers	1 week	*Hardware*: Mini-hoe and mini-shovel designed based on participants' feedback, used to dispose of child feces.	In-depth group and individual interviews	Perceptions of new tools for safe CFD	Mini-hoe was favored over other tools for ease of disposal
Hussain *et al.* (2017)	Rural subdistrict of Kishoreganj, Bangladesh	Caregivers from households in an easily accessible compound and with children 7–36 months of age	26 households, 28 children total	30 days	*Hardware and Behavioral*: three potty design options were provided to each of the 26 households. Group discussions and individual interviews were conducted throughout a 30-day period to gather data on potty likes and dislikes, feces disposal practices, barriers to use, and recommendations for improvement.	Group and individual interviews	Proportion of households practicing safe and unsafe feces disposal	*At baseline*: 4% of households practice safe feces disposal, 96% unsafe disposal. *Post-intervention*: 85% safe feces disposal and 15% unsafe
Biswas *et al.* (2021)	Urban Dhaka, Bangladesh	Caregivers of children <5 in slum areas that were previously enrolled in CHoBI7 mHealth RCT	*Phase 1*: 50 households (34 treatments and 16 control) *Phase 2*: 20 households (15 intervention and 5	July 2018–Dec. 2019 (18 months)	*Behavioral*: Three-phase modified Baby WASH program with voice and text messaging to promote SCFD, home visits, and cue cards with recommended behaviors.	Exploratory interviews, intervention development through mobile health workshops, pilot studies (three phases) of baby WASH modules.	Practices, perceptions, and barriers related to CFD.	Majority of young children's feces disposed of unsafely, while older children tended to defecate directly into latrine. Text and voice messages promoting SCFD were well received by

			control) *Phase 3*: 32 households that had a diarrhea patient (24 receive modified Baby WASH program and 8 control)					participants, though some were unable to answer voice calls due to being busy, and some cell phones did not support Bangla script used in text messaging. Participants recommended adding pictures in addition to text.
Ashraf *et al.* (2012)	Rural Bangladesh	Rural households having at least one child under 3 years of age	104 households at baseline; 96 households at follow-up	4 months	*Hardware and Behavioral*: Potties and a customized hoe-like tool (sani-scoop) to dispose of child and animal feces. Community Health Promoters visited households three times during study and used cue cards, images and text messages to encourage sanitation use.	Household level survey at baseline and survey	Baseline and follow-up comparison of CFD practices	Safe CFD was 25% at baseline compared to 73% after 3 months
Patil *et al.* (2014)	Rural Madhya Pradesh, India	*Intervention group*: Households that had participated in India's Total Sanitation Campaign with at least one child <24 months of age at enrollment *Control group*: data collection only	25 households from each of the 80 study villages	Follow-up assessment at 21 months post-implementation	*Hardware*: Total Sanitation Campaign is a subsidy-based intervention to provide latrines to households below the poverty line. Included several features including flexible technology options for toilets.	Interviews with caregiver-reported safe disposal of feces and presence of visible feces around household	Reported correct disposal of child feces, reported daily open defecation by children, and observed feces in living area around household	*Intervention group*: At baseline, 16% of households reported SCFD and interviewer observed feces in the living area of 59% of households. At 21 months, 27% of households reported SCFD ($p < 0.001$ compared to the control group), and interviewer observed feces in 60% of households ($p > 0.01$). At 21 months, daily open defecation by children was reported by 84% of households ($p < 0.05$ compared to control) *Control group*: At baseline, 13% of households reported SCFD and interviewer observed feces in the living area of 62% of households. At 21 months, 18% of households reported SCFD, and interviewer observed feces in 60% of households. At 21 months, daily open defecation by children was reported by 89% of households.

(*Continued.*)

Table 1 | Continued

Authors	Location	Age group/inclusion criteria	Sample size	Duration of study	Intervention type: intervention description	Data collection methods	Outcome measures	Impacts on CFD practices
Reese *et al.* (2019) and Bauza *et al.* (2019)	Odisha, India	*Intervention group*: 45 villages that had experienced MANTRA intervention 5 years before; households had children <5 years old	*90 villages*: 45 intervention and 45 controls	Intervention implemented 5 years ago	*Hardware*: On-site piped water, and full community sanitation intervention with household latrines and enclosed bathing rooms connected to water supply	Stool samples collected; self-reported outcomes	Comparison with control group of CFD practices	Reese *et al.* (2019): Combined intervention of piped water connection with community sanitation can decrease open defecation. SCFD was 35% in intervention villages compared to 6% in control villages (p <0.001). Bauza *et al.* (2019): Feces from children less than 3 years of age was commonly picked up by caregivers but disposed of unsafely with garbage into open areas. Most children's feces that were safely disposed of in a toilet was because of children defecating in the toilet directly. *Intervention households without improved sanitation (377)*: 1.6% SCFD. *Intervention households with improved sanitation (2,124)*: 40.7% SCFD. *Control households without improved sanitation (2,243)*: 0.2% SCFD. *Control households with improved sanitation (605):* 36.5% SCFD. *Overall intervention households*: 34.8% SCFD. *Overall control households*: 7.9% SCFD
Freeman *et al.* (2016)	Odisha, India	Child <4 years of age or women in the third trimester of pregnancy in the house	1,958 households selected from 100 villages (50 intervention and 50 control)	3 years	*Hardware*: Total Sanitation Campaign is a subsidy-based intervention to provide latrines to households below the poverty line. Households constructed their own pour-flush pit latrines.	Household level survey	Baseline and follow-up comparison of CFD practices	Safe disposal was directly related to increases in latrine presence. At baseline, 1.1% of households practiced SCFD either disposing it in a toilet or by burial. The intervention increased SCFD to 10.4% in intervention households, compared to 3.1% in the control households (RR 3.34; 95% CI 1.99–5.59).

Majorin *et al.* (2014)	Odisha, India	Households with at least one child under 5 years old in one of the 20 selected villages where the Total Sanitation Campaign had been implemented.	136 households and 145 total children	June–July 2012	*Hardware*: Total Sanitation Campaign is a subsidy-based intervention to provide latrines to households below the poverty line. Reported building 1 latrine per 10 rural people from 2001 to 2011.	Structured survey, spot-checks of household latrines for indicators of use and presence of human stools in the compound	Defecation sites and feces disposal sites of children under 5	81.4% of child feces disposed of unsafely and 18.6% disposed of safely following Total Sanitation Campaign. After restricting the analysis to households owning a latrine, the use of a nappy or potty was associated with safe disposal of feces (OR 6.72, 95% CI 1.02–44.38) though due to small sample size the regression could not adjust for confounders.
Caruso *et al.* (2022)	Rural Odisha, India	Villages where the Total Sanitation Campaign had been previously implemented that had not been declared open defecation free by the Government of India with households with at least one child <5 years.	3,723 households in the intervention group, and 1,916 households in the control group	July 2017–March 2019	*Hardware and Behavioral*: The intervention was required to meet a limit of costing less than US$20 per household and included a folk performance, transect walk, community meeting, recognition banners, community wall painting, mothers' meetings, household visits, and latrine repairs. Potties and plastic scoops were also given to mothers.	Village-level activities (pre-intervention community visits, performances, community meetings, mothers meetings) and household visits	Latrine use and CFD practices	*Intervention group*: Latrine use among children was 15.4% at baseline compared to 41.8% at endline. SCFD was 6% at baseline compared to 33.7% at endline. *Control group*: Latrine among children was 18.2% at baseline compared to 37.4% at endline. SCFD was 3.4% at baseline compared to 10.6% at endline.
Lamichhane *et al.* (2018)	Rural Nepal	Households with a female 15–49 years of age and a child of <5 years	3,377 children	February–June 2011 (4 months)	*Hardware*: Improved sanitation was previously provided to households without any behavior change component. Households with improved sanitation and SCFD were matched to households with improved sanitation and unsafe CFD to assess for differences in the prevalence of diarrhea.	Used NDHS data – a nationally representative survey on access to sanitation, CFD practices, and other socioeconomic and demographic factors.	Proportions of households with improved and unimproved sanitation; proportions of safe and unsafe CFD; prevalence of diarrhea	31.9% of households had improved sanitation – of which 35.7% still practiced unsafe CFD, while 64.3% practiced SCFD. Improved sanitation with safe disposal was significantly associated with a lower prevalence of diarrhea among children <5 years of age by 3.3 (standard error [SE] 0.016) to 6.6 (SE 0.023) percentage points under different methods.

Table 2 | Quality assessment of studies included in review of interventions targeting CFD practices in Asian-Pacific countries

Authors	Issue or potential intervention	Study design	Hardware or behavioral intervention	Level[a]	Risk of bias[b]	Overall certainty rating[c]	Impact on safe CFD (SCFD)
Luby *et al.* (2018)	WASH Benefits Bangladesh trial	RCT	Both	A	Low (large sample size, use of random number generator for randomization, geographical matching, all outcomes reported)	High	11–18% of intervention households had visible feces compared to 40–44% in control households
Parvez *et al.* (2018)	WASH Benefits Bangladesh trial	RCT	Both	A	Low (large sample size, observers had no connection to intervention, all outcomes reported)	High	Observed safe disposal of human feces using sani-scoop was moderate at 30–38% ($p > 0.05$) Observed child defecation in potty or latrine was 37–54% of events ($0.28 < p < 0.81$)
Rahman *et al.* (2018)	WASH Benefits Bangladesh trial	RCT	Both	A	Intermediate-High (no control arm for fidelity checks, qualitative investigation)	Intermediate	Qualitative assessment; SCFD met target benchmark of 65% at each fidelity check
Huda *et al.* (2012)	Sanitation, Hygiene Education and Water Supply in Bangladesh program (SHEWA-B)	RCT	Both	A	Low (community monitors not aware of hypothesis, calculated sample size for 80% power and 95% confidence)	High	At baseline, 9.3% of households practiced SCFD, compared to 16% at follow-up ($p = 0.84$ compared to control)
Sultana *et al.* (2013)	Mini-hoe and mini-shovel tools for feces removal	Pilot study	Hardware	D	High (small sample, potential for courtesy bias)	Low	Qualitative only
Hussain *et al.* (2017)	Three potty design options for children	Formative research	Both	D	High (small sample, potential for courtesy bias, self-reported CFD)	Low	*At baseline*: 4% SCFD. *Post-intervention*: 85% SCFD
Biswas *et al.* (2021)	Baby WASH program	Formative research	Behavioral	D	High (convenience sampling, small sample)	Low	Qualitative only
Ashraf *et al.* (2012)	Potties and a customized hoe-like tool (sani-scoop) to dispose of child and animal feces	Prospective Cohort	Both	B	High (self-reported CFD, lack of follow-up)	Low	SCFD was 25% at baseline compared to 73% after 3 months ($p < 0.001$)
Patil *et al.* (2014)	Total Sanitation Campaign	RCT	Hardware	A	Low (randomization via lottery, included other outcome indicators in household surveys to mitigate reporting bias)	High	SCFD increased from 16 to 27% in the intervention group ($p < 0.001$)
Reese *et al.* (2019)	Movement and Action Network for the Transformation of Rural Areas (MANTRA program)	Matched cohort study	Hardware	B	Low (large samples, multivariate matching to achieve balance across cohorts, included other outcome indicators in household surveys to mitigate reporting bias, adjusted for confounding)	High	SCFD was 35% in intervention villages compared to 6% in control villages ($p < 0.001$)

Bauza *et al.* (2019)	Movement and Action Network for the Transformation of Rural Areas (MANTRA program)	Retrospective cohort study	Hardware	B	Low (large sample, accounted for potential confounders and clustering)	High	Intervention households without improved sanitation (377): 1.6% SCFD. Intervention households with improved sanitation (2,124): 40.7% SCFD. Control households without improved sanitation (2,243): 0.2% SCFD. Control households with improved sanitation (605): 36.5% SCFD. **Overall intervention households: 34.8% SCFD. Overall control households: 7.9% SCFD**
Freeman *et al.* (2016)	Total Sanitation Campaign	Randomized control trial	Hardware	A	Intermediate (large sample, but self-reported CFD, only one data collection point)	High	SCFD was 10.4% in intervention households compared to 3.1% in control households (RR 3.34, 95% CI [1.99–5.59]).
Majorin *et al.* (2014)	Total Sanitation Campaign	Cross-sectional study	Hardware	B	Intermediate (self-reported CFD subject to courtesy and recall bias)	Intermediate	18.6% of intervention households practiced SCFD following Total Sanitation Campaign. Among households owning a latrine, the use of a nappy or potty was associated with safe disposal of feces (OR 6.72, 95% CI [1.02–44.38]).
Caruso *et al.* (2022)	Total Sanitation Campaign	RCT	Hardware	A	Low (large samples, similar pattern of missingness in both study groups and within covariate strata, results of sensitivity analyses showed no evidence of bias in effect estimates)	High	SCFD improved by 20 percentage points in the intervention group compared to the control group
Lamichhane *et al.* (2018)	Improved sanitation access	Quasi-experimental	Hardware	B	Intermediate (large samples, but chance of social desirability bias and use of propensity score matching to estimate treatment effects of improved sanitation with and without safe disposal may increase imbalance)	Intermediate	Of households with improved sanitation, 64% practiced SCFD and 36% unsafe CFD. Only 31.9% of households had improved sanitation access

[a]Level A represents RCTs, Level B represents peer-reviewed research studies (cross-sectional studies, quasi-experimental studies, cohort studies), and Level D represents pilot studies or formative research.

[b]Low risk of bias indicates no limitations that could compromise study findings. Intermediate risk of bias includes studies with minor limitations that would not compromise study findings. A high risk of bias indicates studies with several limitations that may compromise study findings.

[c]Overall certainty ratings imply confidence that the true effect lies close to the estimated effect determined in the study. Studies at Level A were initially given a high certainty, studies at level B were rated intermediate, and studies at Level D were initially rated as low. Overall certainty was then moved either higher or lower based on risk of bias estimates.

Biswas *et al.* (2021) conducted a solely behavior change intervention to improve SCFD practices. Mobile voice and text messages were sent to households to promote SCFD behaviors, and home visits were conducted which emphasized the importance of cleaning child feces immediately after a defecation event, noting that child feces were just as dangerous as adult feces. Behavior change messages were well received by participants, and the intervention was adapted to include pictures as those were easier for participants to understand. This formative research study identified that most young children's feces were disposed of unsafely, while older children tended to defecate directly into latrines.

Because of the potential improvements in SCFD practices following provisions of child potties/tools and behavior change messages, scenarios involving combinations tools/potties, presence of toilets, and behavior change components were evaluated.

Tools/potties and presence of toilets

Sultana *et al.* (2013) designed and piloted hoe and shovel tools for the removal of feces from rural Bangladeshi courtyards and modified the tools based on community feedback. The most preferred product was a lightweight mini-hoe with a curved edge for containing and removing feces. Mothers also expressed a desire to purchase plastic potties as a place for children to defecate, though few families could afford them.

After scooping feces, mothers reported either disposing of the feces in the nearest bush or ditch, or inside the toilet (Sultana *et al.* 2013). However, dry leaves and straws were also scooped up with the feces, and mothers did not want to dispose of it in the toilet for fear of blocking the toilet pipe.

Bauza *et al.* (2019) assessed the impacts of India's MANTRA campaign on SCFD, with breakdowns by defecation location and ultimate disposal location. The feces of children who defecated into a potty were either disposed of in a drain/ditch or left in the open, and none of the feces from potties were disposed of safely in a toilet or latrine.

Majorin *et al.* (2014) evaluated impacts of India's Total Sanitation Campaign on SCFD and also stratified by defecation location and ultimate disposal location. Among feces defecated into a potty, 14% were disposed of safely in a latrine and 86% were disposed of with other garbage.

Tools/potties and no toilets

None of the studies in this review fell under the category of tools/potties with no toilets present. However, studies conducted by Sultana *et al.* (2013), Majorin *et al.* (2014), and Bauza *et al.* (2019) showed that feces collected by scoops and potties were often not disposed of into a latrine, even when latrines were present.

Tools/potties, behavior change, and presence of toilets

Ashraf *et al.* (2012) provided potties and customized hoe-like tools to households, with visits from community health promoters to encourage their use. From baseline to 3 months post-intervention, children's potty use increased from 15 to 84% ($p < 0.001$), and disposal of feces into latrines increased from 25 to 73% ($p < 0.001$).

Hussain *et al.* (2017) provided three options of potties to caregivers of children and conducted semi-structured interviews and group discussions to encourage their use. At baseline, caregivers reported that 4% of children defecated into potties, and 4% of households reported safe disposal of feces into latrines. Post-intervention, 86% of children defecated into potties, with 85% of households safely disposing of feces into latrines.

Caruso *et al.* (2022) conducted a larger-scale combined hardware and behavioral intervention among 3,723 latrine-owning households in India and assessed its effects on SCFD. In addition to community meeting, household visits, and latrine assessments, mothers of young children were provided with plastic scoops and potties and encouraged to practice SCFD. At 4 months post-intervention, latrine use increased by 6.4 percentage points, and SCFD increased by 15.2 percentage points.

Parvez *et al.* (2018) and Rahman *et al.* (2018) evaluated impacts of the WASH Benefits Bangladesh trial on SCFD, which provided sani-scoops, child potties, and improved latrines to households in addition to home visits from community health promoters. Rahman *et al.* (2018) spot-checked intervention fidelity and found that 80% of intervention households had sani-scoops and potties easily accessible to the mother. However, additional support was required to encourage and teach rural mothers how to train their children to consistently use the potty.

Parvez *et al.* (2018) monitored child defecation in potties and safe disposal of feces among intervention and control groups following the WASH Benefits trial but did not find significant improvements in potty use or

SCFD. The use of child potties during child defecation was moderate, but the use of sani-scoops for cleaning human and animal feces was low.

Tools/potties, behavior change, and no toilets

Biswas *et al.* (2021) conducted a behavior change intervention with bi-weekly voice and text messages and home visits to promote SCFD behaviors. While most households had access to a latrine, latrines were often shared among multiple households, with many having to travel far distances to reach them. Feces in potties were primarily disposed of in latrines, though some were disposed of in ditches or neighborhood garbage piles particularly during the rainy season when household members had to travel far distances to latrines.

Most households in the combined intervention implemented by Hussain *et al.* (2017) had access to a latrine, though 37% shared latrines with other households. Those who did not own a latrine but shared with other households generally disposed of the child feces either into the latrine or a designated pit.

The majority of included studies (53% ($n = 8$)) were hardware interventions only, meaning they provided some sort of sanitation technology to participants without any behavior change component. An additional six studies (40%) included both hardware and behavioral components, while one study (7%) focused solely on behavior change.

Level of evidence

Of the 15 included studies, seven (47%) were RCTs rated as Level A, as shown in Table 2. The review also included three cohort studies (20%), one quasi-experimental study (7%), and one cross-sectional study (7%) that were rated as Level B. No government reports were included, so no studies were given Level C. The remaining three studies (20%) were formative research or pilot studies and were evaluated as Level D.

Risk of bias

According to the Cochrane guidelines, certain study limitations can increase the risk of bias and therefore decrease the overall certainty rating. A low risk of bias score implies confidence that there were no major or minor sources of bias that could have influenced results. An intermediate risk of bias indicates the presence of one major or several minor study limitations, and a high risk of bias indicates the presence of more than one crucial limitation that may seriously compromise the validity of study findings (Sterne *et al.* 2016; Anthoj *et al.* 2020; Higgins *et al.* 2022).

Seven studies (47%) were scored a low risk of bias. Among these, five were RCTs that had large sample sizes, randomization via random number generator or lottery, little to no missing outcome data, or other outcome indicators measured to mitigate reporting bias that led to the low risk of bias score. Bauza *et al.* (2019) and Reese *et al.* (2019) conducted cohort studies with large sample sizes and adjustments for potential confounders that led to their low risk of bias judgment.

Four studies (27%) were scored an intermediate risk of bias. Freeman *et al.* (2016) and Rahman *et al.* (2018) conducted RCTs that used self-reported CFD data, one data collection point, and had no control arm for fidelity checks, leading to the intermediate risk of bias score. Majorin *et al.* (2014) and Lamichhane *et al.* (2018) conducted studies subject to courtesy, recall, and social desirability bias.

Four studies (27%) were rated a high risk of bias. This rating was due to small sample sizes, the use of convenience sampling, self-reported CFD, potential for courtesy bias, and the lack of follow-up.

Overall certainty rating

Of the seven RCTs, six retained their high certainty score due to a low-to-intermediate risk of bias. The remaining study was ranked down to intermediate certainty as it had more than one major limitation that may have compromised study findings (Rahman *et al.* 2018).

Of the five Level B studies, two moved upwards to a high certainty rating (Bauza *et al.* 2019; Reese *et al.* 2019). Lamichhane *et al.* (2018) and Majorin *et al.* (2014) retained their intermediate rating, while Ashraf *et al.* (2012) moved down to a low rating.

The three formative research and pilot studies all showed a high risk of bias and therefore retained their original low certainty ratings (Sultana *et al.* 2013; Hussain *et al.* 2017; Biswas *et al.* 2021).

DISCUSSION

Our systematic review sought to identify both behavior change and hardware interventions addressing unsafe CFD practices in the Asia-Pacific region, to assess the quality of identified studies, and to compare the effectiveness of each intervention type. We confirmed the lack of evidence on behavior change interventions to improve CFD practices. Of the 15 studies selected for inclusion, only four focused specifically on improving SCFD practices. The remaining 11 studies evaluated the impacts of large-scale interventions, such as the Total Sanitation Campaign, MANTRA programs, WASH Benefits Bangladesh program, and SHEWA-B, on SCFD practices. These interventions targeted improving child feces management as only a small part of larger water, sanitation, and hygiene interventions. Only one study implemented a solely behavioral intervention (Biswas *et al.* 2021), and six studies evaluated a combination of hardware and behavioral approaches.

Strictly hardware interventions, such as India's Total Sanitation Campaign and MANTRA program, showed limited improvements in SCFD practices. Only 35% of villages reported SCFD following the MANTRA program (Bauza *et al.* 2019; Reese *et al.* 2019), and less than 30% reported SCFD following the Total Sanitation Campaign (Majorin *et al.* 2014; Patil *et al.* 2014; Freeman *et al.* 2016). While the Total Sanitation Campaign and the MANTRA program increased household latrine access, younger and pre-ambulatory children are not able to use latrines directly (Majorin *et al.* 2014). Other sanitation hardware components, such as child potties and sani-scoops, may be important tools for facilitating SCFD. However, provisioning these tools without a behavior change component may not be sufficient to improve SCFD practices, particularly when there are no latrines present (Sultana *et al.* 2013; Majorin *et al.* 2014; Bauza *et al.* 2019).

Luby *et al.* (2018), Parvez *et al.* (2018), and Rahman *et al.* (2018) also evaluated the impacts of a large-scale intervention, the WASH Benefits Bangladesh trial, on SCFD practices. WASH Benefits aimed to improve water quality, sanitation, handwashing, and child nutrition and feeding – alone and in combination – among rural communities in Bangladesh. In addition to providing sanitation hardware such as latrines and potties, WASH Benefits also included behavioral components, with visits from community promoters to encourage mothers to teach their children to use potties, to safely dispose of feces in latrines, and to regularly remove human and animal feces from the compound. Luby *et al.* (2018) found significant improvements in latrine access following the trial, and Rahman *et al.* (2018) found that 80% of intervention households had sani-scoops and potties easily accessible to the mother. However, the use of child potties during child defecation was moderate, and the use of sani-scoops for cleaning human and animal feces was low (Parvez *et al.* 2018). The studies did not find statistically significant improvements in SCFD after the WASH Benefits trial (Luby *et al.* 2018; Parvez *et al.* 2018).

Sultana *et al.* (2013) also conducted a solely hardware intervention in which they designed a mini-hoe for scooping and disposing of feces. However, caregivers reported that dry leaves and straws were also scooped up with the feces, and they feared disposing of it in toilets and blocking pipes. Parvez *et al.* (2018) also found low use of sani-scoops for collecting and disposing of feces, in comparison to child potties. This suggests that potties may be a better tool for promoting SCFD than mini-hoes or sani-scoops, as long as support is given to encourage and teach rural mothers how to train their children to consistently use the potties.

The combined behavioral and hardware approaches conducted by Ashraf *et al.* (2012) and Hussain *et al.* (2017) reported the greatest increases in rates of SCFD from pre- to post-intervention. These small-scale trials used tailored messaging and provided multiple tool/potty options to households, which were positively accepted by communities. While these potties may be important for facilitating SCFD, they require latrine access for safe disposal of the collected feces (Sultana *et al.* 2013; Hussain *et al.* 2017). This indicates the need for further research on combined interventions as a method of promoting SCFD. The success of these small-scale combined interventions also suggests that sanitation tools should be tailored to community preferences in order to increase uptake and sustained use.

The studies included in this review identified the age of the child, ambulatory status of the child, and the availability of latrines as determinants for SCFD. As children age, latrine use and other safe feces disposal methods increase (Sultana *et al.* 2013; Bauza *et al.* 2019). Whether a child was ambulatory or not was an important marker of latrine use, where latrine use was almost exclusively tied to ambulatory children (Majorin *et al.* 2014). Latrine use by parents was another important marker for SCFD; caregivers that practiced safe sanitation methods were more likely to safely dispose of children's feces (Hussain *et al.* 2017). Latrine access was largely identified as a necessary component of SCFD, but as evidenced by the strict hardware MANTRA and Total

Sanitation Campaign programs, it is not sufficient to improve SCFD practices without a behavioral component (Majorin *et al.* 2014; Lamicchane *et al.* 2018; Bauza *et al.* 2019; Reese *et al.* 2019).

Previous studies have also indicated open defecation by adults in the household as one of the most significant determinants of unsafe CFD practices (WSP 2015; Islam *et al.* 2018; Ellis *et al.* 2020); however, solely prioritizing reducing open defecation by adults is not necessarily effective in also reducing unsafe CFD (Rand *et al.* 2015). Bhatt *et al.* (2019) identified personal and cultural factors contributing to the burden of open defecation in Nepal as based on either choice or compulsion. Here, motivation by choice includes the use of open defecation as a form of socialization and a method to get outside and exercise, as well as its motivation by habit or convenience. Factors contributing to open defecation by compulsion include the absence of a latrine at home as well as issues with privacy and hygiene (Bhatt *et al.* 2019). Thus, future studies should consider these cultural factors when designing behavior change interventions targeting open defecation by adults, while also explaining the importance of safely managing the feces of their children.

Beardsley *et al.* (2021) evaluated factors associated with unsafe CFD in India and found that higher household income, higher educational attainment, and access to a sanitation facility, whether improved or unimproved, were also significantly associated with SCFD. Those using improved facilities had 6.55 times the odds of practicing SCFD, and those using unimproved facilities had 5.32 times the odds of SCFD, as those with no sanitation facility present (Beardsley *et al.* 2021). However, the authors found no significant association between unsafe CFD and handwashing, access to an improved water source, or use of shared sanitation facilities. Aliyu & Dahiru (2019) and Sahiledengle *et al.* (2021) reported similar findings to Beardsley *et al.* (2021) in Nigeria and Ethiopia, respectively, though the use of an improved water source in these studies was significantly associated with SCFD. This suggests that, while sanitation access is a major component of better SCFD practices, unsafe CFD may be an indicator of larger-scale societal problems such as poverty and lack of education for women. Tackling not only behavior change and sanitation access in the WASH sector, but also poverty and education as broader sectoral issues, may be necessary to significantly improve both SCFD and public health in the future. The inclusion of only articles written in English is one limitation of this study. With so few studies focusing on behavior change as a necessary component of improving SCFD practices, and instead focusing on sanitation hardware, there is much need for the inclusion of behavioral components in future interventions. Large-scale governmental hardware programs in the Asia-Pacific region have increased access to improved sanitation and reduced the need for open defecation and unsafe CFD by compulsion, yet both open defecation and unsafe CFD remain prevalent. Eliminating both open defecation and unsafe CFD cannot be achieved without the incorporation of behavior change interventions in government policies and practices. Community-level combined interventions, such as those conducted by Ashraf *et al.* (2012) and Hussain *et al.* (2017), have shown promise for improving SCFD practices. Scaling up behavior change interventions should be the focus of future governmental programs.

CONCLUSION

Access to sanitation is a defining determinant of SCFD. Large-scale programs and hardware interventions are important for providing communities with the infrastructure necessary to improve SCFD practices, but such interventions may be improved by the addition of a behavior change component. Hardware interventions tend to be ineffective at promoting SCFD if implemented alone. With so little evidence available on the effectiveness of behavioral interventions in reducing unsafe CFD in the Asia-Pacific region, future interventions should focus on addressing the determinants of unsafe CFD practices, especially in poorer households with younger, non-ambulatory children. While the combined behavior change and hardware interventions reported the greatest increases in SCFD, they were of lower quality due to small sample sizes, the use of self-reported data, and the use of observed feces as an indicator of open defecation. This demonstrates a need for future research on how behavior change models combined with hardware interventions impact SCFD in the Asia-Pacific.

This study was primarily limited by available literature that met the selection criteria. Many of the selected studies were not designed to report quantitative results and instead used qualitative methods such as interviews and focus groups to draw conclusions. This variety of methods and result presentations made comparing interventions difficult. Only one behavior change intervention met inclusion criteria, so the true differences between impacts of behavioral and hardware interventions were difficult to ascertain.

ACKNOWLEDGEMENTS

We would like to thank Stacy Torian and Karen Grigg of the University of North Carolina at Chapel Hill Health Sciences Library for their assistance with database search strategy. We thank Ayu Siantoro, Mahesh Nathan, and Nong Davith of World Vision Indonesia. We also thank Katharine Conaway of the University of North Carolina at Chapel Hill for assistance with the creation of figures in this manuscript.

AUTHOR CONTRIBUTIONS

Conceptualization (M.M., L.S., A.L.); Methodology (L.S., A.L., M.M., B.T., R.C.); Software (L.S.); Formal Analysis (L.S., M.M.); Investigation (M.M., L.S., A.L.); Resources (L.S., A.L., M.M.); Data curation (L.S., A.L., M.M.); Writing – original draft preparation (L.S.); Writing – Review and Editing (M.M., B.T., V.B., R.C.); Visualization (L.S., M.M.); Supervision (M.M.); Project Administration (M.M.). All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 26 July 2022; accepted in revised form 20 September 2022. Available online 6 October 2022