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MORALITY BEFORE KNOWLEDGE

Association between access to water, sanitation, and hygiene (WASH) practices and stunting among children under five: A systematic review and meta-analysis

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ABSTRACT

Background: Stunting is a chronic malnutrition condition that leads to impaired growth and development, primarily caused by inadequate water, sanitation, and hygiene (WASH) conditions. This study aims to systematically review and meta-analyze the association between WASH factors and stunting in children under five. **Methods:** This meta-analysis was conducted using the PICO research question. The study population involves children aged 0 to 59 months to analyze how unimproved water, sanitation, and hygiene compare with improved practices in affecting stunting outcomes. Relevant articles were systematically retrieved from several databases including PubMed, BMC, ScienceDirect, and Springer Link, with inclusion criteria focusing on cross-sectional and longitudinal studies published between 2020 and 2025. All gathered data were subsequently synthesized and analyzed using the Review Manager 5.4 application to ensure a rigorous evaluation of the research findings. **Findings:** Meta-analysis included 6 studies from Indonesia and Ethiopia. The risk of stunting increased with unimproved sanitation (aOR = 1.33; 95% CI = 1.20–1.48; p < 0.00001), unimproved hygiene (aOR = 1.16; 95% CI = 0.73–1.84; p = 0.530) unimproved water (aOR = 1.10; 95% CI = 0.94–1.29; p = 0.250) increased the risk of stunting, but it was statistically not significant**. Conclusion:** Unimproved water, sanitation and hygiene increase the risk of stunting. **Novelty/Originality of this article:** This study provides a separated evaluation of water, sanitation, and hygiene factors using evidence from 2020–2025 to clarify specific WASH-related determinants contributing to stunting among children under five.

KEYWORDS: meta-analysis; systematic review; stunting risk factors.

1. Introduction

Stunting represents a chronic form of malnutrition that occurs when children fail to reach their optimal linear growth potential. This condition leads to permanent impairments in both cognitive and physical development. A child is classified as stunted when their height falls below two standard deviations (−2 SD) from the WHO growth standard (Ademas et al., 2021). Defined as a condition in which a child's height is more than two standard deviations below the mean height for their age according to the World Health Organization (WHO) growth standards, stunting is not merely a reflection of short stature but a significant indicator of long-term health and developmental issues (Wardani et al., 2023). Stunting is primarily linked to inadequate nutrient intake and recurrent infections during early childhood, which together hinder optimal physical growth (González-Fernández et al.,

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2023; Stepniewska et al., 2024). The long-term impacts of stunting include inhibited physical growth, poor educational performance, greater susceptibility to non-communicable diseases, reduced work productivity, and diminished national economic output (Akseer et al., 2022).

Stunting has both immediate and enduring effects. Short-term consequences include increased susceptibility to infectious diseases and delayed physical development. In the longer term, individuals who experienced stunting are at an elevated risk for various health issues, including chronic diseases such as obesity, diabetes, and cardiovascular conditions as adults (Freer et al., 2025; Kusumaningsih & Anjela, 2024). Stunted children also show compromised developmental trajectories, leading to significant discrepancies in educational outcomes and cognitive abilities as they progress through school systems (Restila et al., 2023). Childhood stunting correlates with long-term cognitive impairments, which persist into adulthood. These individuals often demonstrate lower educational achievements and, consequently, diminished economic productivity. Stunting is consistently linked to adverse cognitive and academic outcomes, reinforcing the assertion that nutritional deficits during early life have lasting implications for human capital development across various socioeconomic contexts (Awaludin et al., 2025).

Globally, malnutrition imposes a substantial socioeconomic burden, with estimated annual losses reaching approximately USD 3.5 trillion, equivalent to nearly 5% of the global gross domestic product (Sangalang et al., 2022). Consequently, the reduction of stunting has been prioritized within the Global Nutrition Targets for 2025 and designated as a key indicator (2.2) of the Sustainable Development Goals, reflecting its strategic importance in global public health initiatives (Supadmi et al., 2024). Despite sustained international efforts, stunting remains highly prevalent, especially in low- and middle-income countries. Joint estimates from UNICEF, WHO, and the World Bank report that approximately 151 million children under five years of age globally, or 22.2 percent of children in this age group, exhibit impaired linear growth. The burden is markedly uneven across economic strata, with prevalence rates of 47 percent in lower-middle-income countries and 16 percent in low-income countries, compared with 27 percent and 10 percent in upper-middle-income and high-income countries, respectively (Mulyaningsih et al., 2021). Asia bears the greatest burden, accounting for an estimated 83.8 million stunted children, predominantly in South and Southeast Asia, followed by 58.7 million in Africa and 5.1 million in Latin America and the Caribbean (Permatasari et al., 2023).

In Indonesia, stunting remains a critical public health concern despite gradual declines over recent decades. National survey data reported a prevalence of 30.8% in 2018, reflecting notable improvement yet still exceeding the World Health Organization's threshold for high public health concern. Recent estimates indicate persistent disparities, with urban regions such as the Special Capital Region of Jakarta showing a prevalence of 16.8% in 2021 (Permatasari et al., 2023). The National Medium Term Development Plan (NMDP) for 2025 to 2029 aims to reduce stunting to 14.4% by 2029 from a baseline of 18.8% in 2025, equivalent to an annual reduction of approximately 1.1%. However, Indonesia has achieved an average decline of only 0.1% per year (Fentiana et al., 2025). These figures underscore that stunting is not merely a nutritional deficiency but a multifaceted issue influenced by social, economic, and environmental determinants, necessitating integrated, multisectoral interventions.

The complexities of stunting underscore a multifaceted issue that extends beyond nutritional deficiencies alone. Factors such as maternal health, education, sanitation, and economic conditions play significant roles in a child's growth trajectory (Hobbs et al., 2023). Water, sanitation, and hygiene (WASH) are essential environmental determinants that influence child growth and play a vital role in preventing stunting. Inadequate sanitation has been recognized as the second leading global contributor to stunting after nutritional deficiencies (Ademas et al., 2021). Globally, approximately 2.2 billion people, or one in three, still lack access to safe drinking water. Likewise, 4.2 billion people, representing three out of every five individuals, do not have access to adequate sanitation facilities, while about 673 million people continue to practice open defecation. Furthermore, nearly 3 billion

people, or two out of five globally, do not have access to basic handwashing facilities with soap and water. Continuous exposure to fecal contamination through unsafe water and unhygienic practices can lead to intestinal infections, impaired nutrient absorption, mucosal damage, and villi dysfunction, resulting in chronic gut inflammation and environmental enteropathy (Batool et al., 2023). Between 2020 and 2021, an estimated 14 percent of people in 31 LMICs experienced water insecurity (Young et al., 2022), while approximately 450 million children globally lacked adequate access to clean water to meet their daily needs (UNICEF, 2021). These conditions highlight the critical importance of improving WASH services as a key public health strategy to reduce stunting and promote optimal growth and development in children.

Ensuring universal access to clean water, improved sanitation, and sufficient water supply for hygiene remains a major global challenge (Mondal et al., 2025). Therefore, identifying the underlying factors contributing to stunting is essential for designing targeted and effective interventions. This study aims to analyze the association between unimproved water, sanitation, and hygiene (WASH) and stunting among children under five years of age. Using the latest body of evidence, this review focuses on studies published between 2020 and 2025 and provides a more detailed assessment by examining water, sanitation, and hygiene factors separately. Through a comprehensive systematic review and meta-analysis, the present study synthesizes the most recent and relevant peer-reviewed publications to identify specific WASH-related determinants that influence stunting in early childhood.

2. Methods

2.1 Study design and selection

This is a systematic review and meta-analysis to assess the relationship between WASH and stunting among children under-five. The databases consulted included PubMed, BMC, ScienceDirect, and Springer Link. The PRISMA flow diagram was used to ensure a systematic and transparent article selection process. The search strategy incorporated keywords such as “determinants” OR “risk factors” AND “relationship” AND “water” AND “sanitation” AND “hygiene” AND (“multivariate” OR “odds ratio”) AND “malnutrition” OR “growth disorders” OR “stunting” to identify relevant studies.

The meta-analysis was conducted through a structured five-stage procedure. First, the research questions were formulated using the PICO framework to clearly delineate the target population, exposure variables, comparison groups, and primary outcomes. Second, systematic searches were performed across electronic and non-electronic sources, followed by independent screening of retrieved records based on predefined inclusion criteria. Titles, abstracts, and full texts were assessed according to PICO specifications, with discrepancies resolved through consensus or consultation with an additional reviewers. Third, methodological quality and relevance of eligible studies were critically appraised. Fourth, data pertaining to study characteristics, participant profiles, exposure measures, instruments, and outcomes were extracted. Finally, quantitative synthesis was conducted using Review Manager 5.4 to compute pooled effect estimates, while duplicate datasets were excluded by prioritizing the most recent and comprehensive evidence.

2.2 Inclusion and exclusion criteria

The inclusion criteria used in searching the database for articles were as follows: articles published between 2020 and 2025, English-only papers featuring cross-sectional studies and longitudinal studies, studies with children aged <5 years and focused on water, sanitation, hygiene, assessing relationship to stunting. Only studies that conducted multivariate analysis and provided adjusted odds ratios (aOR) were included to evaluate the statistical associations between WASH and stunting. The exclusion criteria for this study consisted of randomized controlled trials (RCTs), non-full-text articles, quasi-experimental studies, preliminary studies, and research protocols.

2.3 Data extraction and quality assessment and data analysis

The data extraction process involved collecting detailed information on study characteristics, sample sizes, outcomes, and statistical measures. The quality of each study was evaluated using a validated checklist emphasizing methodological rigor, sample representativeness, and clarity of reporting. Studies identified with considerable bias were either excluded or assigned a lower weight in the final synthesis. The methodological quality of the studies included in the systematic review was assessed using the Joanna Briggs Institute (JBI) appraisal tool, with results expressed as percentages. Each criterion was scored as 1 point for "yes," 0.5 points for "unclear," and 0 points for "no." The study data analysis process was conducted using the Review Manager 5.4. The software generated forest plots and funnel plots to visually represent the meta-analysis results. Statistical measures such as I^2 and Cochran's Q test were used to evaluate heterogeneity across studies. The analysis assessed the relationship between water, sanitation, and hygiene on stunting.

3. Results and Discussion

3.1 Searches and selection of studies

The identification, screening, and selection of studies were conducted in accordance with the PRISMA flow framework, as illustrated in Figure 1. A total of 2,172 records were identified from multiple databases, including ScienceDirect (342), PubMed (1,631), BMC (78), and SpringerLink (121). After removing 87 duplicate records, 2,085 unique articles remained for screening. During the screening phase, 1,989 articles were excluded based on predefined criteria, including irrelevant titles (n = 1,659), non-English language publications (n = 127), and studies that were not cross-sectional or longitudinal in design (n = 71). Subsequently, 96 full-text articles were assessed for eligibility. Of these, 85 articles were excluded for specific reasons, primarily due to inappropriate outcome measures (n = 38) and the absence of adjusted odds ratios (aORs). Ultimately, 11 studies met the inclusion criteria for qualitative synthesis, and 6 of these were included in the final quantitative synthesis (meta-analysis).

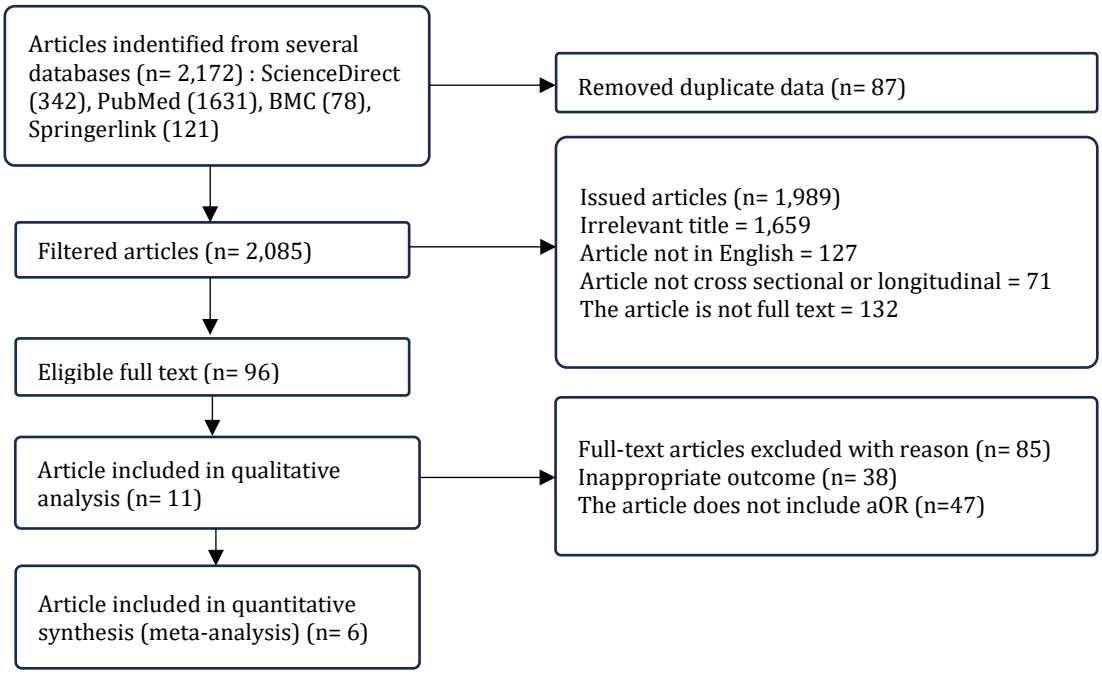

Fig. 1. Prisma flow diagram

3.2 Characteristics of the studies

The studies included in this systematic review were published between 2020 and 2025 and were conducted in Ethiopia and Indonesia, both categorized as low and middle income countries (LMICs). Collectively, these studies examined the association between access to water, sanitation, and hygiene (WASH) services and linear growth outcomes among children under five years of age (Table 1). Across the selected literature, 67% of studies evaluated water access, 83% assessed sanitation conditions, and 67% incorporated hygiene indicators into their analyses. This distribution reflects a predominant research emphasis on sanitation, followed by water and hygiene components within the broader WASH framework.

Table 1. Information from selected articles of WASH on stunting used in the systematic review

Author	Country (sample) Study Design	Population	Intervention	Comparation	Outcome
Permatasari et al. (2025)	Indonesia (316) Cross-sectional	Children 0-59 months	1. Unimproved hygiene	1. Improved hygiene	Stunting
Ademas et al. (2021)	Ethiopia (630) Longitudinal studies	Children 0-59 months	1. Unimproved water 2. Unimproved sanitation 3. Unimproved hygine	1. Improved water 2. Improved sanitation 3. Improved hygiene	Stunting
Widyaningsih et al. (2022)	Indonesia (3887) Cross-sectional	Children 0-59 months	1. Unimproved sanitation	1. Improved sanitation	Stunting
Bekele et al. (2021)	Ethiopia (33,744) Cross-sectional	Children 0-59 months	1. Unimproved water 2. Unimproved sanitation 3. Unimproved hygiene	1. Improved water 2. Improved sanitation 3. Improved hygiene	Stunting
Mulyaningsih et al. (2021)	Indonesia (8945) Cross-sectional	Children 0-59 months	1. Unimproved water 2. Unimproved sanitation 3. Unimproved hygine	1. Improved water 2. Improved sanitation 3. Improved hygiene	Stunting
Rah et al. (2020)	Indonesia (1450) Longitudinal studies	Children 6-35 months	1. Unimproved water 2. Unimproved sanitation	1. Improved water 2. Improved sanitation	Stunting

3.3 Quality of the studies

The quality assessment using JBI criteria indicated that, among the six studies included in the systematic review, five (83%) demonstrated excellent methodological quality. This finding suggests that most included studies met key appraisal standards, reflecting strong research design, appropriate data collection, and overall reliability of the evidence synthesized.

3.4 Meta-analysis

The meta-analysis presented in Table 2, sanitation demonstrates statistically significant association with stunting. Five primary studies reported that unimproved sanitation substantially increases the likelihood of stunting. The highest aOR was found in Ademas et al. (2022) (aOR = 2.04), indicating that children exposed to unimproved sanitation were more than twice as likely to experience stunting compared with those accessing improved sanitation, while Mulyaningsih et al. (2021) documented the lowest significant aOR at 1.23. Limited access to improved water sources is possibly associated with an increased risk of stunting among children. Studies reported adjusted odds ratios (aORs) ranging from 1.01 to 2.41, indicating notable variability in effect size yet consistently highlighting the protective role of improved water access. Similarly, for hygiene practices, particularly hand hygiene. Effect estimates varied, with Mulyaningsih et al. (2021) reporting the highest aOR (1.75), indicating elevated stunting risk associated with poor hygiene, while Permatasari et al. (2025) documented the lowest aOR (0.46), reflecting heterogeneity in hygiene related stunting risks across study populations.

Table 2. aOR value of the assosiation of WASH component on stunting

Publication (Author and Year)	WASH component	aOR	95% CI	
			Lower Limit	Upper Limit
Rah et al. (2020)	Water	1.09	0.84	1.41
Mulyaningsih et al. (2021)	Water	1.22	0.71	2.10
Bekele et al. (2021)	Water	1.01	0.80	1.28
Ademas et al. (2022)	Water	2.41	1.12	5.22
Rah et al. (2020)	Sanitation	1.40	1.03	1.90
Bekele et al. (2021)	Sanitation	1.33	0.92	1.92
Mulyaningsih et al. (2021)	Sanitation	1.23	0.98	1.54
Ademas et al. (2022)	Sanitation	2.04	1.36	3.07
Widyaningsih et al. (2022)	Sanitation	1.29	1.11	1.50
Bekele et al. (2021)	Hygiene	1.02	0.86	1.21
Mulyaningsih et al. (2021)	Hygiene	1.75	1.34	2.29
Ademas et al. (2022)	Hygiene	1.87	1.25	2.81
Permatasari et al. (2025)	Hygiene	0.46	0.26	0.81

3.4 Discussion

3.4.1 Association of unimproved water with stunting

The forest plot presented in Figure 2 illustrates that exposure to unimproved water sources is possibly associated with a 1.10-fold higher likelihood of stunting compared to improved water access (aOR = 1.10; 95% CI = 0.94–1.29; p = 0.250). Although the association does not reach statistical significance, the direction of effect aligns with established environmental and nutritional pathways highlighting the role of water quality in child growth outcomes. Additionally, the analysis demonstrates a low degree of heterogeneity across included studies (I^2 = 35%; p = 0.200), suggesting relatively consistent effect estimates among the primary datasets. Consequently, a fixed-effect modelling approach was employed to generate the pooled estimate.

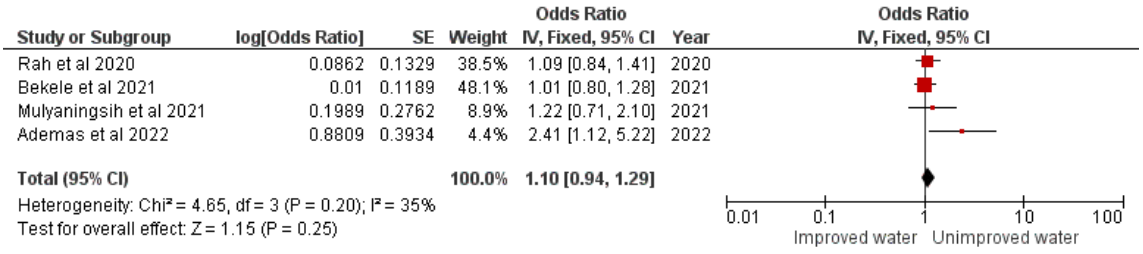

Fig. 2. Forest plot the assotiation of unimproved water on stunting

The funnel plot in Figure 3 reveals a largely symmetrical distribution of effect estimates around the pooled mean, indicating the absence of publication bias among studies evaluating water quality and stunting. The symmetry also suggests no meaningful small-study effects, thereby reinforcing the stability and validity of the observed association.

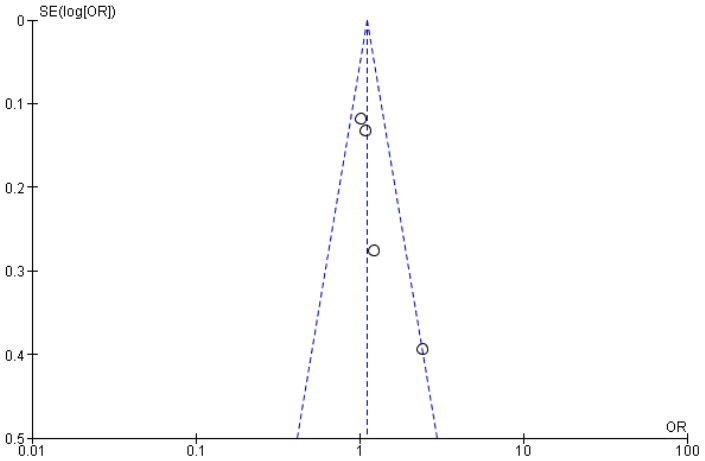

Fig. 3. Funnel plot the assotiation of unimproved water on stunting

The study by Ademas et al. (2022) reported the highest adjusted odds ratio (aOR) of 2.41 (95% CI: 1.12–5.22), indicating that children from households with unimproved water sources were 2.41 times more likely to experience stunting compared to those with access to improved water sources. Similarly, Permatasari et al. (2025) reported that stunting in children was 2.17 times more likely to occur in families that did not have sufficient clean water for all members than in families with adequate access to clean water. This condition occurs because more than half of rural households rely on refilled gallon water, which carries a risk of physical contamination such as glass fragments, metal particles, or plastic residues entering the water during unhygienic production, processing, or packaging processes.

According to Ademas et al. (2022), an improved water source refers to a facility designed and constructed to effectively prevent external contamination, particularly from fecal matter. Such sources include piped household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater harvesting systems. However, microbiological contamination, including bacterial growth such as *Escherichia coli* and coliform bacteria, has also been detected in refilled gallon water. Contaminated drinking water serves as a medium for various pathogens that cause diarrheal diseases such as campylobacteriosis, giardiasis, gastroenteritis, amoebiasis, and cholera. These illnesses contribute to an increased risk of stunting in children by disrupting the absorption of macro- and micronutrients essential for growth and development (Batool et al., 2023; Yani et al., 2023). Moreover, consuming water from unimproved sources or untreated water elevates the likelihood of diarrhea caused by intestinal infections from diverse bacteria, parasites, and viruses. As noted by Mulyaningsih et al. (2021), the effects of diarrhea on linear growth are particularly significant when young children experience recurrent episodes within the first two years of life. Diarrhea can further lead to growth retardation when accompanied by inadequate food quality and limited access to healthcare services. It negatively affects both linear and weight growth by reducing food intake, increasing metabolic demands, and impairing nutrient absorption in the intestines.

In this study, unimproved water sources were not significantly associated with stunting. This finding aligns with previous research indicating that household access to improved water sources did not predict childhood stunting. Similarly, Rah et al., (2020) reported no synergistic effects between household sanitation and water supply on child stunting. Nevertheless, this observational finding should be interpreted with caution, considering the key results from the WASH Benefits trials in Kenya and Bangladesh, which

demonstrated no additional benefit of combined WASH interventions over single nutrition-specific interventions in those settings, as further discussed in the commentary on external validity by Cumming & Curtis (2018). Although the association between unimproved water sources and stunting is not statistically significant, the consistent direction of the effect suggests a potential influence that may be relevant in large population contexts, particularly in areas with poor sanitation.

Rural communities tend to depend heavily on unimproved water sources, including rivers, ponds, lakes, and unprotected wells, primarily because piped and regulated water systems are still predominantly developed in urban areas. In many remote settings, safe and engineered water facilities such as spring boxes, capped boreholes, and protected wells remain limited or inaccessible. As a result, households in rural regions often utilize water supplies that lack adequate construction standards and protection, increasing their vulnerability to contamination and associated health risks. This persistent infrastructural disparity underscores the need for equitable investments in rural water systems to ensure sustainable and safe water access for all populations (Abegaz, 2021). Bekele et al. (2021) reported that rural areas exhibited the highest prevalence of child linear growth failure (48.81%), with more than half of stunted children belonging to the lowest wealth quintiles 51.44% in the first and 50.32% in the second. Moreover, stunting was more prevalent among children from households using unimproved water sources (49.19%) compared to those accessing improved water (45.58%). This pattern highlights the intersection of socioeconomic disadvantage, geographic isolation, and inadequate WASH conditions as key determinants of child undernutrition. Children living in rural and economically marginalized households without access to safe water are disproportionately affected by growth failure, emphasizing the need for targeted interventions. These findings underscore that WASH-based programs must adopt an integrated approach, addressing not only clean water provision but also adequate sanitation facilities and the promotion of hygienic behaviors to achieve sustainable improvements in child health and development.

3.4.2 Association of unimproved sanitation with stunting

The forest plot in Figure 4 demonstrates that exposure to unimproved sanitation facilities is associated with a statistically significant 1.33-fold increase in the risk of stunting compared to children with access to improved sanitation (aOR = 1.33; 95% CI = 1.20–1.48; $p < 0.001$). This finding underscores the importance of adequate sanitation infrastructure in mitigating growth faltering among children. The analysis also reveals a low degree of heterogeneity among the included studies ($I^2 = 20\%$; $p = 0.290$), indicating that the effect estimates are relatively consistent across the reviewed evidence. Accordingly, a fixed-effect modelling approach was applied to estimate the pooled effect size. The reported adjusted odds ratio suggests that children residing in environments with inadequate sanitation are approximately 33 percent more likely to experience stunting, highlighting sanitation quality as a critical environmental determinant of child nutritional status. While the effect may appear modest on an individual basis, it holds meaningful public health significance at the population level, particularly in settings where inadequate sanitation practices remain widespread.

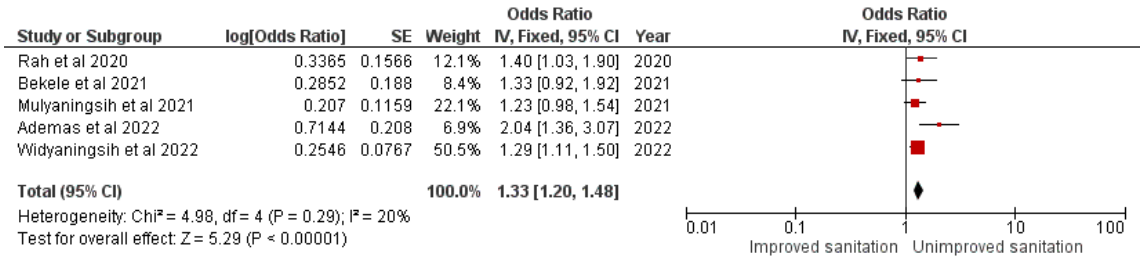

Fig. 4. Forest plot the assotiation of unimproved sanitation on stunting

Figure 5 presents the funnel plot examining potential publication bias in studies assessing the association between unimproved sanitation and stunting. The visual inspection indicates a largely symmetrical distribution of effect estimates around the pooled mean, suggesting an absence of publication bias and minimal influence of small-study effects. This symmetrical pattern strengthens the credibility of the synthesized evidence and supports the robustness of the reported association between sanitation conditions and childhood stunting risk.

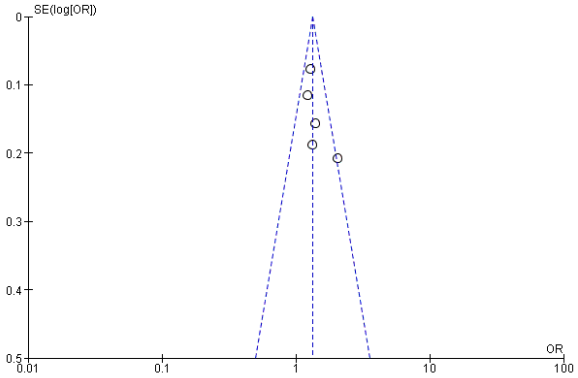

Fig. 5. Funnel plot of the association of unimproved sanitation on stunting

Several studies have consistently demonstrated a strong association between sanitation conditions and childhood stunting, highlighting the critical role of improved sanitation in promoting optimal child growth. Ademas et al. (2022) reported the highest adjusted odds ratio (aOR = 2.04; 95% CI: 1.36–3.07), indicating that children from households with inadequate sanitation facilities were more than twice as likely to experience stunting compared to those with adequate sanitation. Similarly, Bekele et al. (2021) found that access to improved sanitation significantly reduced the likelihood of stunting by approximately 46% (aOR = 0.54; 95% CI: 0.38–0.78). Improved sanitation refers to facilities designed to prevent human contact with excreta, including sewer-connected or septic latrines, pour-flush toilets, pit latrines with slabs, and ventilated improved pit latrines (Ademas et al., 2022).

Inadequate sanitation systems are strongly associated with an increased prevalence of diarrheal diseases, which contribute to malnutrition and can ultimately result in stunted growth, particularly in settings with poor hygiene practices (Huo et al., 2022). The lack of proper sanitation exposes children to fecal pathogens from both human and animal sources, leading to recurrent diarrhea, intestinal worm infections, and impaired nutrient absorption. These infections often suppress appetite and reduce dietary intake, further increasing the risk of chronic undernutrition (Sufri et al., 2023 ; Laillou et al., 2020). In such environments, unimproved sanitation creates conditions that favor persistent enteric infections and prolonged episodes of diarrhea, both of which are recognized as critical pathways leading to stunting (Heni et al., 2025). One of the central mechanisms linking poor sanitation to impaired child growth is environmental enteropathy (EE), a subclinical disorder of the small intestine. EE is marked by villous atrophy, crypt hyperplasia, increased intestinal permeability, and mild malabsorption, which together compromise the small intestinal mucosa's absorptive and barrier functions. This chronic intestinal dysfunction prevents effective nutrient absorption and utilization, ultimately contributing to poor nutritional status and stunted growth in children. Thus, EE represents a key biological pathway through which inadequate sanitation directly affects child growth and development (Rah et al., 2020).

Children living in households lacking safe water and sanitation infrastructure are also more susceptible to various forms of undernutrition, including underweight and wasting, which often coexist with stunting (Saaka et al., 2021). Supporting this, a cross-sectional study in Maputo, Mozambique, revealed that households relying on shared sanitation facilities had significantly higher stunting rates due to poor hygiene management and

increased exposure to pathogens (Braun et al., 2024). Poverty remains a central barrier to the achievement of universal sanitation access. In both rural and densely populated urban areas, economic hardship limits the capacity of households to construct, upgrade, or maintain adequate sanitation systems. Rural households, in particular, face considerable financial constraints that reduce their likelihood of having improved sanitation facilities. Studies indicate that rural populations are approximately 11.35% less likely to access improved sanitation compared to urban residents (Irianti, 2021).

Although urban areas generally demonstrate higher levels of sanitation coverage compared with rural settings, urban informal settlements or slum environments present a complex and equally pressing sanitation challenge. Residents in these densely populated, underserved urban spaces often face infrastructural inadequacies, poor drainage systems, overcrowding, and limited maintenance of communal facilities, conditions that collectively heighten exposure to sanitation-related health hazards (Donacho et al., 2022). Evidence from Yulyani et al. (2021) revealed that approximately 23.3 % of 289 surveyed households engaged in open defecation, primarily due to restricted access to or ownership of sanitation facilities, particularly for tenants whose landlords prohibit latrine construction. Such barriers highlight the critical importance of land and tenancy policies in shaping sanitation behaviors. Access to adequate latrines and sanitation services represents a fundamental environmental determinant, and facilitating sanitation infrastructure on rented or informal land should be prioritized as a strategic intervention to reduce open defecation in urban settings (Nunbogu et al., 2019). These findings underscore that environmental and social constraints intersect to perpetuate unsafe disposal practices, further compounding exposure to enteric pathogens and undermining child health in vulnerable urban populations.

Environmental determinants are central to sustaining open defecation behaviors, particularly in areas where improved sanitation services are absent or inaccessible. Families residing in impoverished and informal urban settlements often lack feasible sanitation alternatives, rendering open defecation a default practice (Khan et al., 2021). The consequences extend far beyond hygiene, as exposure to fecal contamination contributes to recurrent infections, particularly diarrheal disease, which is strongly associated with impaired nutrient absorption, chronic inflammation, and ultimately stunting and undernutrition in children (Sahiledengle et al., 2022). Furthermore, reliance on unimproved or contaminated water sources exacerbates infection susceptibility and compounds nutrition-related vulnerabilities (Ranzani et al., 2020). Empirical evidence from Ethiopia indicates a clear association between open defecation and increased stunting prevalence, demonstrating the critical link between sanitation practices and childhood growth outcomes (Sahiledengle et al., 2022).

These findings highlight the importance of strengthening community-based sanitation programs, as well as integrating sanitation initiatives with child nutrition programs. The government needs to ensure the sustainability of sanitation infrastructure through quality monitoring, enhanced education on clean and healthy living behaviors, and financial support for low-income households. Overall, the results emphasize that sanitation is not only related to physical infrastructure but is also a key determinant of child health and development, where adequate sanitation access can reduce the incidence of diarrhea, improve nutrient utilization, and break the cycle of infection and malnutrition that contributes to stunting among children under five.

3.5.3 Association of unimproved hygiene with Stunting

Figure 6 displays the forest plot assessing the relationship between unimproved hygiene practices and stunting. The pooled analysis indicates that children exposed to inadequate hygiene, such as the absence of proper handwashing practices, exhibited a 1.16-fold increased likelihood of being stunted compared to those with adequate hygiene (aOR = 1.16; 95% CI = 0.73–1.84; p = 0.530). Although the association did not reach statistical significance, the direction of effect remains consistent with established biological pathways

linking poor hygiene, enteric infections, and impaired nutritional status. Furthermore, substantial heterogeneity was observed across the included studies (I^2 = 89%), suggesting considerable variation in effect estimates attributable to contextual, methodological, and population-level differences. Accordingly, a random-effects model was applied to provide a conservative pooled estimate and account for between-study heterogeneity.

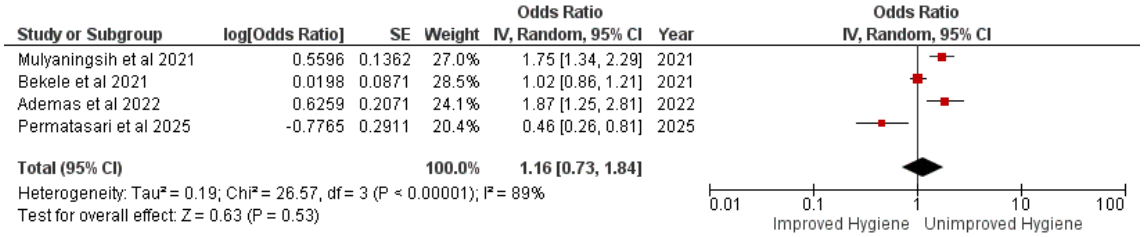

Fig. 6. Forest plot of the association of unimproved hygiene on stunting

The funnel plot presented in Figure 7 demonstrates a largely symmetrical distribution of effect estimates around the pooled effect line, indicating the absence of publication bias. The symmetry suggests that the findings are unlikely to be influenced by selective reporting or the preferential publication of studies with statistically significant results. Moreover, no evidence of small-study effects was observed, further affirming the reliability and stability of the estimates. Collectively, these findings reinforce the importance of hygiene as a component of WASH interventions, even though the current data do not demonstrate a statistically significant association, highlighting the need for additional high-quality prospective studies utilizing standardized hygiene measures and objective assessment methodologies.

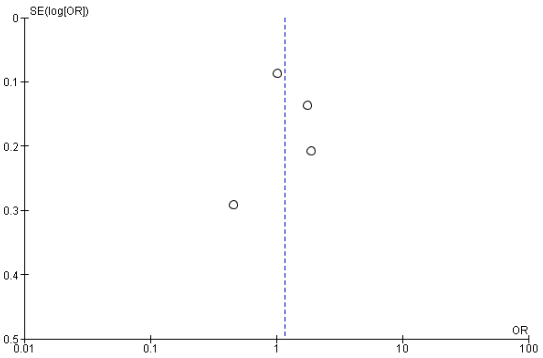

Fig. 7. Funnel plot of the association of unimproved hygiene on stunting

Ademas et al. (2022) reported an adjusted odds ratio (aOR) of 1.87 (95% CI: 1.25–2.81), indicating that children living in households with unimproved hygiene conditions were 1.87 times more likely to experience stunting compared to those with better hygiene practices. Similarly, Menalu et al. (2021) found that personal hygiene indicators significantly influence the risk of stunting, particularly handwashing habits (p = 0.018). Children who did not wash their hands with soap showed a stunting prevalence of 38.5 percent, while the prevalence among those who practiced proper handwashing was only 27.1 percent. A study by Pradana et al. (2023) in Kendal Regency, Central Java, Indonesia, also revealed that mothers and children who neglected to wash their hands with soap were 5.76 times more likely to have stunted children than those who practiced good hygiene. These findings collectively highlight that personal hygiene, especially consistent handwashing, plays an important role in reducing exposure to pathogens that cause infections and hinder optimal growth among children under five years of age.

Poor hygiene practices, including irregular handwashing and unsafe food handling, are recognized as major contributors to the persistence of stunting. Sahiledengle et al. (2022) emphasized that recurrent diarrhea, which is closely related to poor water, sanitation, and

hygiene (WASH) conditions, can disrupt nutrient absorption and increase energy expenditure, ultimately leading to growth failure. A study in Benin demonstrated that children with access to improved hygiene facilities experienced lower stunting rates, underscoring the protective effect of adequate hygiene alongside improved sanitation (Gaffan N et al., 2023). Families with higher socioeconomic status, who can afford better hygiene and WASH facilities, tend to have lower rates of stunting (Yunus et al., 2021). Taken together, these studies provide strong evidence that hygiene behavior is a critical determinant of children's nutritional outcomes and growth patterns, particularly in low- and middle-income communities.

Inadequate maintenance of hygiene facilities, such as dirty toilets and the presence of flies, contributes to an increased risk of both undernutrition and overnutrition, as children tend to avoid restrooms perceived as unclean, foul-smelling, dark, and lacking privacy. In this context, the avoidance of school toilets has been associated with stunting, which may be explained by the possibility of chronic constipation leading to reduced appetite and impaired growth, or recurrent enteric infections that disrupt nutrient absorption (Sangalang et al., 2022). These gastrointestinal disturbances include increased intestinal permeability, inflammation, bacterial translocation, and nutrient malabsorption (Owino et al., 2016), as well as the potential development of environmental enteric dysfunction due to exposure to unhygienic conditions (Sangalang et al., 2022).

Insufficient exposure to hygiene education has been linked to increased stunting risk. Limited understanding and knowledge among children about preventing the spread of pathogens may reduce their ability or motivation to adopt essential health practices, such as proper handwashing and rinsing fruits and vegetables prior to consumption. Inadequate hand hygiene heightens susceptibility to infectious diseases, which can subsequently contribute to malnutrition and impaired physical growth. Although Riiser et al. (2020) identified a positive association between knowledge of handwashing and actual hygiene behavior, a systematic review by de Buck et al. (2017) indicated that no single approach to promoting handwashing has consistently proven effective across diverse settings.

Comprehensive WASH interventions are essential to prevent stunting and enhance children's overall health and development. Strengthening hygiene behaviors such as consistent handwashing with soap, maintaining food cleanliness, and ensuring the use of safe water, combined with improvements in sanitation infrastructure, can significantly improve child growth indicators (Aryani & Afrida, 2025). Promoting these behaviors through education, community health campaigns, and household-level initiatives is fundamental to reducing infection rates and interrupting the cycle between poor hygiene and undernutrition. The consistent evidence linking hygiene to stunting risk highlights the importance of integrating WASH components into public health and nutrition programs. Sustained efforts to improve hygiene practices and sanitation access will help lower the prevalence of stunting and contribute to long-term gains in child growth, development, and well-being.

This study has several limitations that should be acknowledged. It employed both cross-sectional and longitudinal designs, however the included studies were limited to only two countries, Indonesia and Ethiopia, which may restrict the generalizability of the findings. In addition, the literature search was restricted to articles published within the last five years, potentially excluding earlier relevant studies. Moreover, certain variables could not be adjusted for because the necessary data were unavailable, possibly due to insufficient statistical power.

Consequently, a causal relationship between WASH conditions and the risk of child stunting cannot be firmly established. In addition, the relatively short publication window used in the search strategy may have resulted in the inclusion of a limited number of studies, thereby influencing the comprehensiveness of evidence and potentially affecting the interpretation of the meta-analytic findings. Future research with longitudinal designs and biological indicators is needed to strengthen causal evidence and identify more specific mechanistic pathways. Furthermore, future research exploring the association between WASH and stunting should consider comparing the current levels of community sanitation

coverage, as recent evidence suggests that higher community-level sanitation coverage may have a protective effect against stunting (Fuller & Eisenberg, 2016; Bauza & Guest, 2017). Notably, we were unable to control for all potential confounders because key information, such as maternal body mass index, was not consistently reported across the included studies. Nevertheless, this study demonstrated significant associations between household sanitation conditions and child stunting using representative survey data from the local context, thereby providing a valuable foundation for subsequent research examining WASH-related determinants of stunting in Indonesia.

4. Conclusions

The results of this study indicate that inadequate water, sanitation, and hygiene (WASH) conditions are associated with an increased risk of stunting among children. The meta-analytic findings demonstrate that children living in households with poor sanitation infrastructure, unsafe drinking water, and suboptimal hygiene practices tend to experience higher rates of stunting compared to those residing in environments with adequate WASH services. Among the three WASH components evaluated, unimproved sanitation showed a statistically significant association with stunting and emerged as the most prominent environmental determinant influencing linear growth failure. In contrast, limited access to improved water sources and inadequate hygiene practices were only suggestively associated with an elevated risk of stunting and did not reach statistical significance.

The absence of statistically significant associations for water and hygiene components may be explained by several factors, including heterogeneity in study designs, inconsistencies in the operational definitions and measurement of WASH exposures, and variations in environmental, socioeconomic, and cultural contexts across study settings. Additionally, water quality and hygiene behaviors often exert their effects through indirect and cumulative pathways, such as recurrent subclinical infections and chronic intestinal inflammation, which may not be fully captured in cross-sectional analyses or short-term exposure assessments. Despite these limitations, the consistent direction of effect observed across studies suggests that water and hygiene remain relevant contributors to child growth outcomes, particularly in resource-limited settings.

Overall, the findings highlight the pivotal role of WASH conditions as fundamental determinants of child health and nutritional status. Exposure to contaminated water, inadequate sanitation, and poor hygiene practices increases susceptibility to infectious diseases, especially diarrheal illnesses, which can disrupt nutrient absorption and contribute to chronic undernutrition and impaired growth. Improving access to safe drinking water, expanding coverage of improved sanitation facilities, and promoting regular handwashing with soap are therefore essential strategies for stunting prevention. This study underscores the importance of environmental health interventions in shaping nutritional outcomes and supports the incorporation of comprehensive WASH improvements into public health and national nutrition programs. An integrated, multisectoral approach that combines WASH interventions with nutrition-specific and behavior change strategies is likely to be more effective in achieving sustainable reductions in stunting and promoting optimal growth and development among children.

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Author Contribution

A.F.N., as the lead researcher, determined the research topic, carried out the literature search, collected the research data. The research process was supported by C.S.P. and W., who contributed to data processing, analysis, and the review of relevant documents and research articles. Their involvement enhanced the overall rigor, clarity, and completeness

of the study's findings, ensuring that all stages of data handling and interpretation were conducted systematically and accurately.

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