Review Paper

Multiple and complex links between babyWASH and stunting: an evidence synthesis

Amy Waller, Monica Lakhanpaul, Samuel Godfrey and Priti Parikh

ABSTRACT

Studies have shown linkages between water, sanitation and hygiene (WASH) and stunting in children under 2 years in sub-Saharan Africa. WASH interventions have been shown to reduce stunting rates; however, the biological mechanisms and socio-economic influences responsible for this trend remain poorly understood. This paper reviews the literature regarding these links, and the efficacy of both general WASH interventions and those targeted at children in their first 1,000 days, known as babyWASH, for stunting reduction. Fifty-nine papers published between 2008 and 2019 were reviewed, retrieved from Science Direct, Scopus and Web of Science databases, comprising field trials and data analysis, and literature and systematic reviews. Key findings showed that stunting is directly attributed to diarrhoea, environmental enteric dysfunction and undernutrition although a more comprehensive understanding of these biological mechanisms is necessary. Interventions to interrupt the faecal transmission cycle proved to effectively reduce stunting rates, particularly improved sanitation facilities to reduce open defaecation, increased proximity to water and widespread behavioural change. Methodologies should move away from randomised controlled trials towards selected contexts, mixed data collection methods and inclusion of broader social, cultural and environmental conditions. Improved cross-sectoral collaboration is encouraged, particularly to ensure the complexity of social and contextual factors is fully considered.

Key words | babyWASH, stunting, sub-Saharan Africa, WASH

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HIGHLIGHTS

- A fuller understanding of the biological mechanisms responsible for stunting is necessary.
- A lack of research around babyWASH interventions specifically targeted at children in their first 1,000 days is lacking despite growing evidence of the onset of stunting during this period.
- More attention must be given to the indirect causes of stunting, including chronic poverty, intergenerational trends and gender roles.

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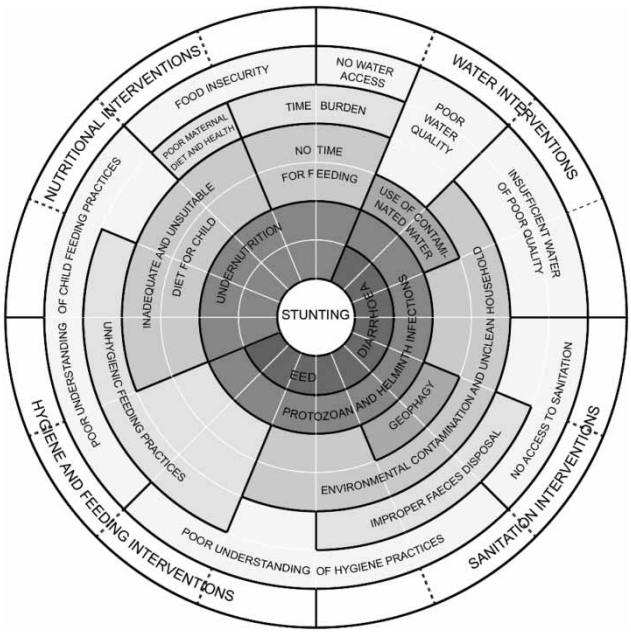
GRAPHICAL ABSTRACT



INTRODUCTION

An estimated 144 million children worldwide under the age of 5 are stunted due to undernutrition, representing 21.3% of children globally (UNICEF *et al.* 2020). Within this number, sub-Saharan Africa continues to show the highest regional prevalence of 32.7%, representing 57 million children according to 2019 statistics (UNICEF *et al.* 2020).

Onset is thought to be between conception and age 2 years, and initiates a path of reduced cognitive ability, degenerative intergenerational development and a compromised socio-economic trajectory (Prendergast & Humphrey 2014; Action Against Hunger 2017). The United Nations Children's Fund (UNICEF) framework for undernutrition is a fundamental document in the universal effort to eliminate global stunting (UNICEF 1990). It advocates a multi-sectoral approach to target the direct biological pathways and indirect socio-economic influences responsible for stunting, supported by the United Nations Sustainable Development Goals (SDGs) (United Nations 2015).

There is evidence that improved water, sanitation and hygiene (WASH) is a central component of achieving global elimination of stunting. Improved WASH can interrupt the faecal–oral transmission pathway, thereby reducing onset of the biological causes of stunting thought to be environmental enteric dysfunction (EED), diarrhoea and subsequent malnutrition (Dodos *et al.* 2017). WASH infrastructure and improved hygiene behaviours are also linked to socio-economic status and opportunity through the poverty cycle, offering potential for intergenerational economic growth and improved health (Prendergast & Humphrey 2014). Access to water and sanitation aims to address the direct biological causes as well as these indirect socio-economic factors, both with direct impact to child health.

Much research exists exploring the relationship between WASH and stunting in children and adults; however, few studies are available which specifically explore WASH designed to target maternal and newborn health during the first 1,000 days, known as babyWASH.

This paper reviews the literature examining WASH interventions aimed at reducing stunting in children under 2 years, as well as WASH interventions trialled in children

and adults of all ages for its potential application to children in their first 1,000 days. It initially questions the direct and indirect causes of stunting and how WASH can affect these, then goes on to discuss successful and unsuccessful interventions through a comprehensive literature review. Finally, it provides an analysis of these findings and identifies gaps and directions for further study.

METHODOLOGY

Inclusion criteria

Restricted criteria have been used to eliminate irrelevant information and to provide an accurate representation of the available literature on this specific subject area. The paper considers research meeting the following inclusion criteria and limits: (a) WASH and associated nutritional interventions, (b) stunting (defined as height for age (HAZ) <-2 standard deviations of the median according to the WHO Child Growth Standards (WHO & UNICEF 2014)), (c) children in their first 1,000 days of life (under 2 years) and (d) sub-Saharan Africa. To ensure all relevant research is included, this study conservatively defines sub-Saharan Africa as all countries in the African continent except Western Sahara, Morocco, Algeria, Tunisia, Libya and Egypt.

In some cases, the criteria were extended to include research on children under 5 years where literature was of value. Articles with a broader geographical scope but the inclusion of sub-Saharan countries were also considered if deemed to add value to the overall study. Inclusion limits required papers to be published in English.

For the purpose of this study, WASH is defined as (a) water infrastructure, availability, accessibility and quality, (b) sanitation infrastructure, availability, accessibility and quality, and (c) hygiene practices including infant feeding, environmental cleanliness and associated educational and cultural behaviours.

Search methodology and data sources

This study comprises an extensive literature review of relevant papers published between 2008 and 2019. ScienceDirect, Scopus and Web of Science databases were used to extract relevant articles, using the search terms 'baby WASH stunting' and 'water sanitation hygiene stunting'.

ScienceDirect returned 459 and 852 articles for these search terms, respectively; Scopus 7 and 113, respectively; and Web of Science 8 and 95, respectively.

All 1,534 articles were reviewed by title and abstract against the criteria; 1,401 excluded as a result; the remaining 133 examined for relevant articles in reference lists; 35 articles subsequently added; 168 articles read for full review; 109 excluded; and 59 articles remained for inclusion in this study. Figure 1 visually illustrates the selection process.

The available applicable research consists of a combination of primary trials, secondary data analysis and literature or systematic reviews.

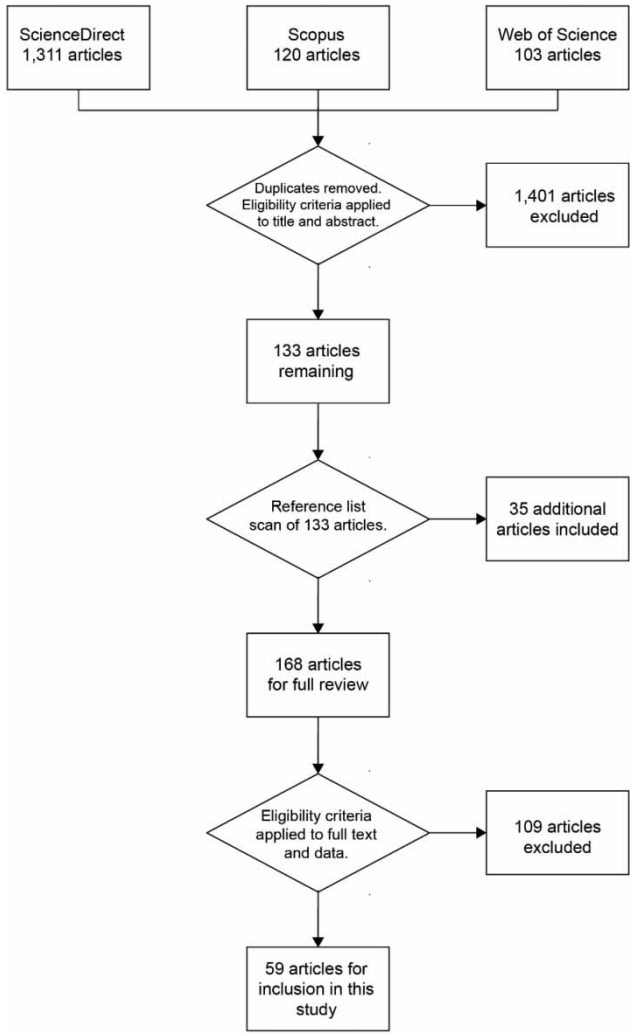


Figure 1 | Database search methodology and resource selection process.

A database format was used to process categorised and numerical data, to allow simple filtering of information for comparison. NVivo literature review software was used to process qualitative content.

Categorisation of literature

The literature included 59 papers from 2008, when the literature in this field began to increase, to 2019. Following selection of the papers, the literature was classified by primary trials (22), secondary data analysis (9) and literature and systematic reviews (28). Publication dates were recorded to explore trends of research in the field, which show that publications have rapidly increased since 2012 with a peak of 10 published in 2017, and 9 published in both 2018 and 2019 (Figure 2).

Papers were also categorised by location and age demographics of study groups in accordance with the eligibility criteria.

Figure 3 compares the location of studies to the percentage of stunted children under 5 years in each country, adapted from UNICEF, WHO and World Bank Joint Child Malnutrition statistics (2020), which revealed no correlation between prevalence of stunting and chosen study locations. Twenty-one of the trials were carried out in rural locations; only one in an urban environment.

Of the total 59 papers, 9 studied Zimbabwe including 5 of the 22 field trials, likely due to the recently completed SHINE trials, despite a comparatively low percentage of stunted children at 27.1%. Malawi and Rwanda show striking results given that only one trial paper is available for each despite such high percentages of stunted children; 37.4 and 38.2%, respectively. This suggests the need for prioritisation of research in locations with high stunting rates to find possible trends and causes to develop optimal solutions appropriated for the local contextual barriers and enablers.

Analysis of data collection methods of the 22 trials revealed that 9 studies measured quantitative data alone, 3 qualitative data alone, and 10 measured a combination of both. Trials using quantitative data recorded primarily anthropometric measurements alongside other biological

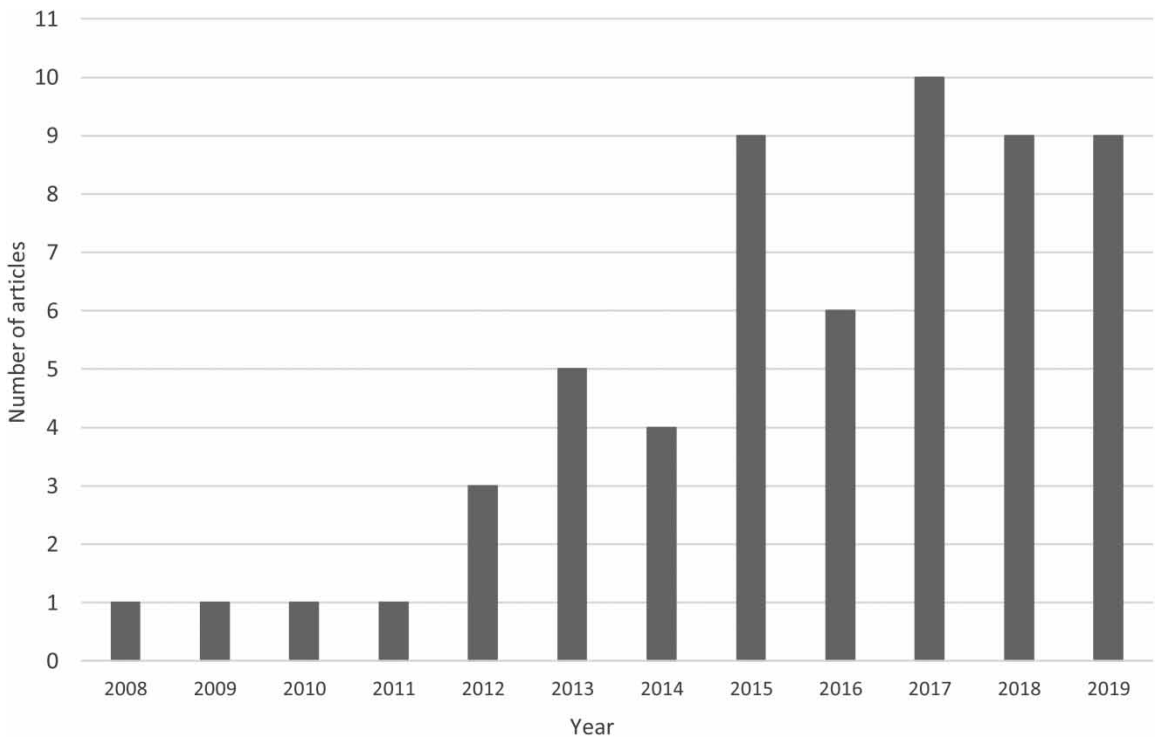


Figure 2 | Number of articles published per year of 59 papers selected for this study.

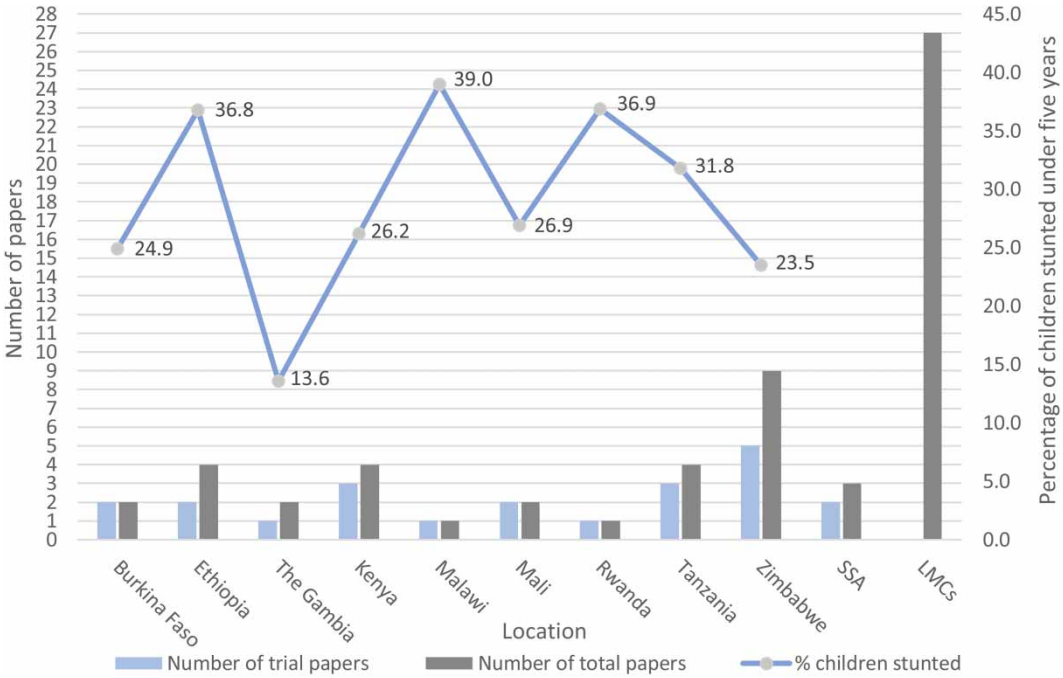


Figure 3 | Graph showing the study locations of all 59 articles in dark grey. Light blue bars show the locations of 22 field trials. The blue trend line indicates the percentage of children under 5 years stunted per country from most recent survey years (adapted from UNICEF, WHO and World Bank Joint Child Malnutrition Estimates (2020)). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2020.265.

biomarkers such as haemoglobin levels in some instances. Qualitative methods were typically used to collect data on household income, hygiene behaviours, health, food-security, diarrhoea incidence and household cleanliness.

All 59 papers included the objective age criteria of the first 1,000 days; however, the 22 trials frequently also studied other age groups which were included if deemed to add value to the study. Only eight trials recorded data for the 0–24 months age group as a discrete group, indicating the urgent need for more studies for this cohort alone. Figure 4 shows the varied data collection groups across all papers.

Written and analysis methodology

The literature categorisation graphically displays the trends found from the data extraction process, categorised by dates of publication, location of studies and age demographic. The following paper structure is split into three key sections: findings, discussion and gap analysis.

The findings discuss results from the literature in three distinct themes: direct causes, indirect causes and interventions. Direct causes consider the direct biological factors connected to stunting, and indirect causes discuss the broader contextual, socio-economic and intergenerational influences. Interventions review results from trials exploring WASH measures in context.

FINDINGS

Findings reveal two distinct pathways to childhood stunting, direct and indirect causes, and therefore two stages that present opportunity for intervention in early life. Direct causes comprise the factors that biologically enable growth faltering; namely protozoan and helminthic infections, diarrhoea and EED, a subclinical disease of the small intestine (Dodos *et al.* 2017). Malnutrition in the form of undernutrition also presents itself as stunting or wasting, often exacerbated by the causes above (Null *et al.* 2018). Indirect causes comprise the environmental influences that enable these biological factors to manifest: chronic poverty, the broader political and socio-economic environment, cultural practices and climatic conditions (Dodos *et al.* 2017).

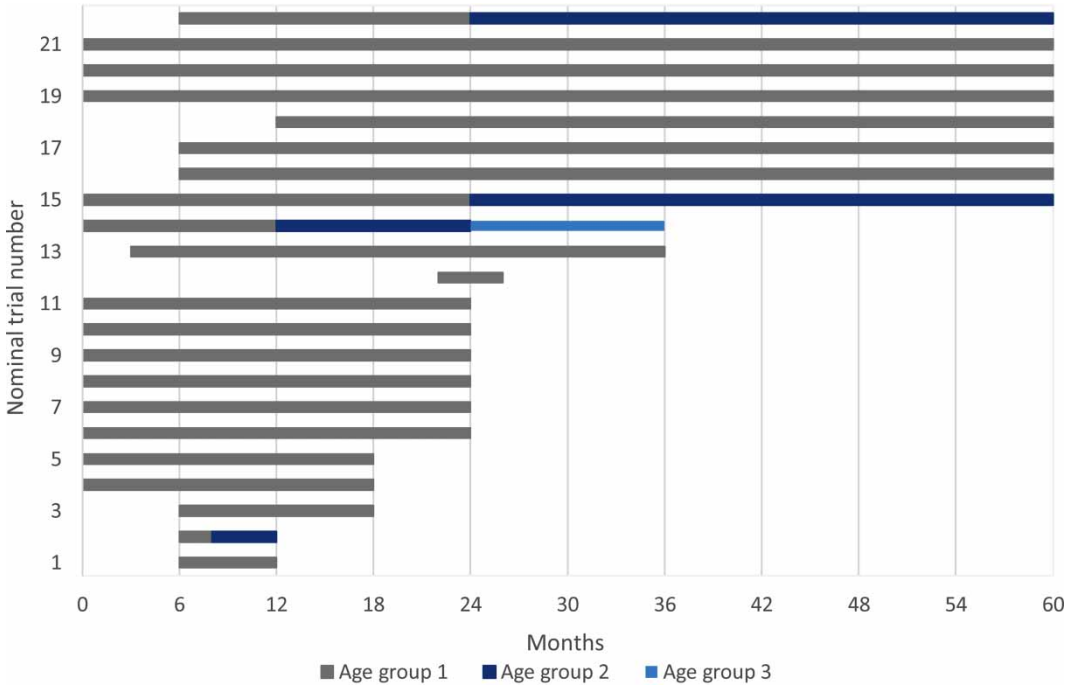


Figure 4 | Graph showing age groups studied in each of the 22 trials. The full length of each bar shows the full age range studied. Individual colours dictate the separate data collection groups. Trial numbers are nominal. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2020.265.

Early literature typically attributes stunting to diarrhoea; however, over time studies have found a correlation between stunting and EED, distinguishable due to their symptomatic and asymptomatic natures, respectively (Prendergast *et al.* 2014). Stunting rates have typically been unaffected by WASH, behavioural and nutritional interventions to reduce diarrhoea, which has led to hypothesis of an alternative causal mechanism (Pickering *et al.* 2019).

Additionally, indirect pathways and contextual factors prove significantly influential (Budge *et al.* 2019). The poverty cycle through low income, restricted access to WASH resources and food, and ill health is a fundamental barrier to development (Esrey *et al.* 1992). It is itself influenced by the wider political and economic climate, worsened by political volatility, economic instability and conflict (Atinmo *et al.* 2009). Most removed from control yet significantly influential is the seasonal climate responsible for droughts and floods, straining food and water resources, increasing economic vulnerability and exposure to disease (Hyland & Russ 2019).

WASH and nutritional interventions have potential to interrupt both direct and indirect causes. Improved water and sanitation have been shown to affect the direct biological causes of stunting by reducing faecal–oral pathogen transmission via any pathway (Wagner & Lanoix 1958; Pickering *et al.* 2019). Indirectly, WASH can interrupt the poverty trap, alleviate the time burden associated with WASH activities and provide more time for income-generating work (Hyland & Russ 2019).

WASH interventions aim to make water and sanitation available, accessible and of an appropriate standard to maintain hygienic practices and reduce opportunity for faecal-oral contamination (WHO & UNICEF 2019). Feeding and nutritional interventions offer preventative and retrospective measures in response to malnutrition, both independently and in conjunction with WASH.

The above causes and interventions were found to be relevant to all age groups including children in their first 1,000 days. Both WASH interventions aimed at the broader community with subsequent impact on young child health and babyWASH interventions targeted specifically towards children under 2 years have proven to effectively reduce childhood stunting.

Figure 5 presents an overall graphic of these relationships, the pathways to stunting and intervention points. The following section will review these direct causes, indirect causes and interventions in further detail.

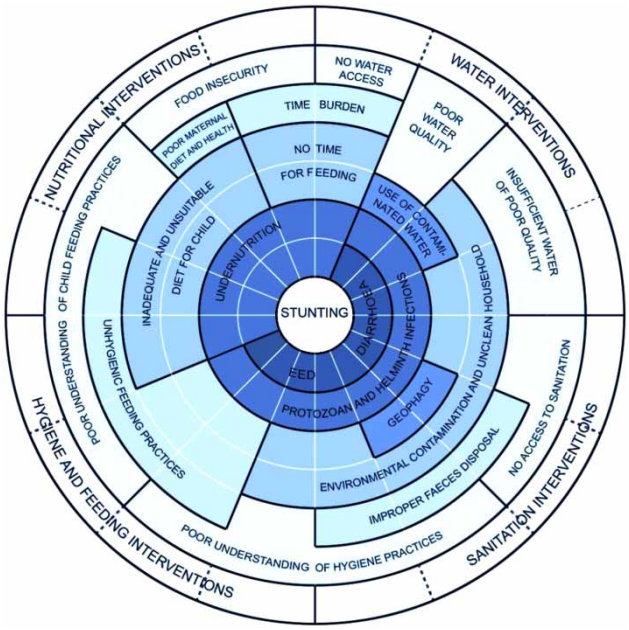


Figure 5 | Graphic showing pathways to stunting. Each 1/16th segment represents a unique pathway. Interventions are shown in the outside ring; causes are shown in the inside rings (developed by authors). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2020.265.

Direct causes

Faecal–oral pathogen transmission

Protozoan and helminthic infections are attributed to faecal–oral pathogen transmission through fluids, fields, flies, fingers and food as shown in Figure 6 (Wagner & Lanoix 1958). Once ingested, these pathogens cause long-term enteric damage and are understood to be a major cause of EED, diarrhoea and undernutrition through malabsorption (Mbuya & Humphrey 2016). The cycle through defaecation and ingestion is both caused and resolved by WASH provision; open defaecation is considered particularly detrimental, as it behaves as an enabler for permeation of pathogens into soil, crops and water (Mbuya *et al.* 2015). Geophagy, the practice of eating soil, is common throughout a child's early years through exploration and play, increasing likelihood of protozoan ingestion and carrying an increased risk in areas where open defaecation is common and children are exposed to animal faeces (Ngure *et al.* 2014; Kaur *et al.* 2017). The consequences of exposure are exacerbated through poor hygiene practices, failure to wash children's hands and child self-feeding (Ngure *et al.* 2013).

Environmental enteric dysfunction

EED is a subclinical disease of the small intestine; however, the exact aetiology is not fully understood and difficult to determine given its asymptomatic nature (Budge *et al.* 2019). Literature attributes EED to chronic pathogen contact and ingestion which alters the fundamental biological gut structure (Prendergast *et al.* 2015). However, statistical data

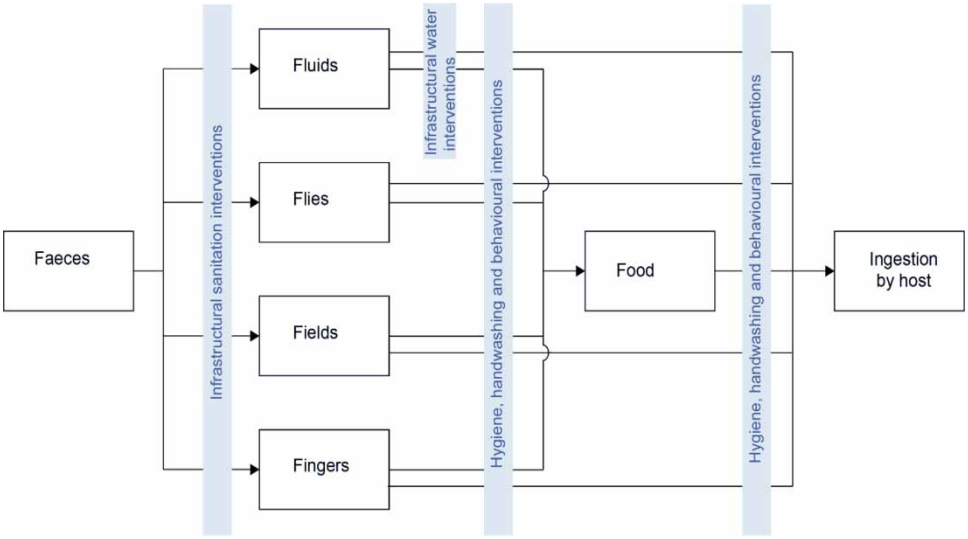


Figure 6 | The 'F' diagram (adopted from Wagner & Lanoix (1958)).

quantifying trends between EED and stunting are lacking, likely due to the absence of reliable biomarkers, lack of symptoms and use of diarrhoea prevalence as a proxy measurement (Prendergast *et al.* 2014).

Little research or evidence exists regarding the presence of EED at birth, which if present infers that causes are present during pregnancy, questioning the priority and efficacy of pre-natal versus post-natal interventions.

Diarrhoea

Diarrhoea is typically caused by viral or bacterial infection through faecal–oral pathogen transmission and is frequently used as an indicator of stunting due to its symptomatic nature (WHO 1992). A self-perpetuating cycle between diarrhoea and malnutrition is evident, which suggests a causal pathway linking diarrhoea to stunting via nutrition (Brown *et al.* 2013). There is also evidence that diarrhoea and EED can occur simultaneously, questioning whether studies could unknowingly indicate a false positive correlation between diarrhoea and stunting due to the (unknown) presence of EED (Schmidt 2014).

Malnutrition, diet and nutrition

Malnutrition refers to overnutrition, undernutrition and other dietary related disease caused by too many, too few or an unbalanced composition of required calories and nutrients, often exacerbated by ingestion of harmful bacteria, intestinal worms or faecal coliforms (Sinharoy *et al.* 2017). There is evidence that malnutrition and undernutrition in the first 2 years, and particularly the first 6 months, have a significant effect on both neurodevelopment and physical development of children (Ngure *et al.* 2014), often visible through stunting and wasting.

Diarrhoea and EED can exacerbate undernutrition and stunting by preventing optimal nutritional uptake (Ngure *et al.* 2014). WASH interventions to reduce exposure to and ingestion of harmful bacteria can reduce diarrhoea and EED, subsequently reducing malnutrition and resultant stunting (Ngure *et al.* 2014).

Indirect causes

The poverty cycle and economic influences

The chronic poverty cycle, shown in Figure 7, facilitates access to the valuable resources required to ensure health of young children including food, water and sanitation. The cycle through low income, reduced access to food and WASH facilities, resultant poor health and malnutrition, reduced time in education and employment, and economic decline is self-perpetuating (Atinmo *et al.* 2009).

This cycle appears both generationally within families and communities, and at a broader national economic scale. Broader national policies, political volatility, economic instability and conflict dictate the foundations of the national socio-economic spectrum, limiting the potential and mobility of the public (Nabwera *et al.* 2017).

Limited access to food and WASH facilities is a fundamental component that directly enables the biological causes of stunting. However, contextual factors that fuel the poverty cycle are those responsible for hindering implementation and success of WASH interventions.

Intergenerational and caregiver trends

Evidence shows that stunting follows a generational cycle; stunted mothers, younger mothers and mothers with a

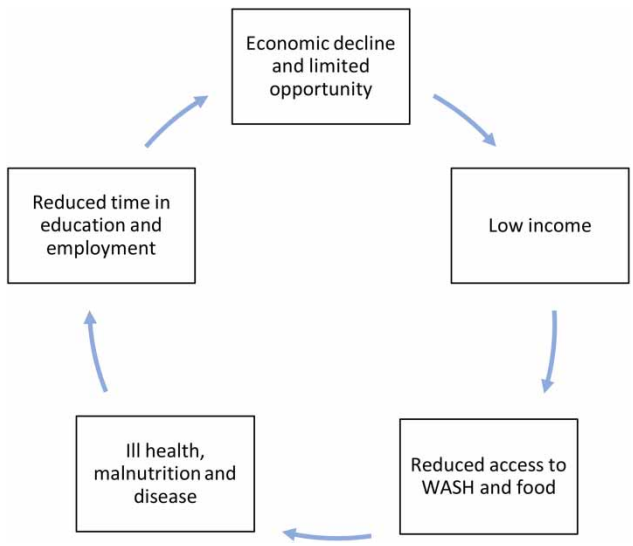


Figure 7 | The poverty cycle (adapted from Atinmo *et al.* (2009))

lower body mass index are more likely to have stunted children (Kwami *et al.* 2019). Younger gestational age and a commonly linked lower birthweight also increase likelihood of stunting (Pickering *et al.* 2019). As stunted children grow to be stunted adults, their own children are at increased risk, fuelling an intergenerational trap (Budge *et al.* 2019).

Children from larger families and those with a higher birth order are more likely to be stunted, likely due to increased competition of resources (Howell *et al.* 2016; Mshida *et al.* 2018). Children with a male caregiver are less likely to be growth impaired; however, justification for this observation is lacking (Mshida *et al.* 2018). Lower levels of caregiver education increase the likelihood of childhood stunting most likely due to poor knowledge of optimal feeding and care practices, an increased adherence to detrimental cultural practices and reluctance to adopt modernised behaviours (Mshida *et al.* 2018).

Gender and time burden associated with WASH

Archetypical cultural gender roles usually task women with water collection and household duties, while men assume responsibility for paid work including migrant work away from home (Asian Development Bank 2015). Farming is being increasingly feminised with a changing economic and meteorological climate, increasing the time burden on women (Hyland & Russ 2019). Increased time carrying out these duties as primary caregivers reduces time available for childcare and feeding, and often passes responsibility to other caregivers (Kwami *et al.* 2019). There is growing evidence of a direct link between childhood stunting and the time associated with WASH and income-generating activities (Mshida *et al.* 2018).

Climate change and the natural environment

Drought directly limits crop production, subsequently limiting available food and income generated from sales to purchase food and water (Hyland & Russ 2019). Hyland & Russ (2019) demonstrated a downward spiral in economic stability following detrimental weather events; families living in poverty are additionally vulnerable with no financial reserves exacerbating the effects of seasonal food shortages to create long-term food insecurity. Seasonal weather variation and changing weather patterns through flooding and drought are also reflected in diarrhoea incidence, which peaks both in winter as faecal-contamination spreads through flooding and in summer as hot temperatures provide optimal conditions for bacterial growth in food (Pickering *et al.* 2015).

Interventions

The most commonly trialled interventions are combinations of infrastructural, educational and nutritional methods, which examine the effect on both direct and indirect pathways. These include both those targeted at children in their first 1,000 days specifically, and general WASH interventions to improve health and hygiene in all ages with subsequent effect on child health.

Sanitation

Four trials studied showed that improved sanitation interventions increased child growth but did not affect diarrhoea rates unless combined with either educational or water interventions (Daniels *et al.* 1991; Esrey *et al.* 1992; Merchant *et al.* 2003; Pickering *et al.* 2015). However, Demographic and Health Surveys (DHS) from 59 countries found a reverse trend; improved sanitation alone had no effect on stunting but did reduce diarrhoea rates although this study reviewed worldwide data and did not distinguish sanitation types or contextual factors (Headey & Palloni 2019).

The transition from open defaecation to any form of sanitation facility, in comparison to the transition from an unimproved to improved facility, was found to most effectively interrupt faecal–oral transmission and observe a resultant decrease in stunting (Vilcins *et al.* 2018; Headey & Palloni 2019). A reduction in the number of open defaecators was reflected in reduced stunting rates indirectly, through a reduction of faecal pathogens in water and the surrounding environment (Vilcins *et al.* 2018).

Safe disposal of child faeces in an improved sanitation facility showed a reduction in stunting in an analysis of DHS data from 34 countries (Bauza & Guest 2017). While sanitation facilities typically consider adults and older children, correct disposal of nappies and child faeces is equally important to ensure reduction of faecal

contaminants. The greatest results were observed when improved sanitary practices were adopted by more than 75% of the community (Merchant *et al.* 2003). Adherence and education of these improved practices proved to be critical; Null *et al.* (2018) saw a decrease of child faeces disposal in a suitable sanitation facility by 50% between the first and second year of implementation, due to the common misbelief that child faeces are less contaminated than adult faeces.

Water availability and accessibility

A systematic review showed reduced stunting rates when water is available inside or close to the home and emphasised a universal preference for a piped on-premise water supply (Brown *et al.* 2013). The same paper showed that nearby water provision increased use per capita threefold, resulted in a cleaner household environment, improved general hygiene practices and reduced time spent collecting water all of which affect children under 2 years (Brown *et al.* 2013).

Increased use of surface water also correlates with increased rates of stunting; usually contaminated with rubbish, faeces and often shared with animals (WHO & UNICEF 2014). Where piped on-premise water is not possible, improved water sources to reduce the use of surface water including boreholes and wells were found to be substantially better than surface sources to provide cleaner water (Clasen *et al.* 2015).

The time burden of water collection and therefore reduction in time available for care of babies and young children is frequently raised in research although no papers were found that distinctly study the relationship with stunting. A positive correlation exists between improved infant health and less time spent collecting water (Mshida *et al.* 2018). A survey carried out using household interviews in Kenya revealed a preference to pay inflated prices for improved nearby water access in favour of more available time (Whittington *et al.* 1990).

Water quality

Trials mostly examine the relationship between water quality and direct causal pathways, rather than stunting specifically. A relationship between water quality and diarrhoea is apparent; a study in Ethiopia found 3.7 times increased likelihood of diarrhoea in children who use an unimproved water source (Marugán *et al.* 2018).

Interventions have been trialled at source, point-of-use and in combination with other WASH interventions. Solutions to improve water quality at point-of-use show reduced diarrhoea rates, specifically disinfectants and filtration systems (Clasen *et al.* 2015). However, there is insufficient evidence to assess the efficacy of water quality interventions at source, and little research examining the relationship with stunting directly. In both cases, there remains risk of further contamination through incorrect water storage, use of dirty containers or exposure to other infection points (Marugán *et al.* 2018).

Hygiene and behavioural interventions

Handwashing successfully interrupts the pathogen transmission pathway according to the 'F' diagram, specifically when encouraged before eating and after defaecation (Brown *et al.* 2013). In one study, maternal handwashing with soap at critical times after defaecation and before feeding was found to reduce the probability of diarrhoea by 15 times (Marugán *et al.* 2018). When assessed in relation to EED, handwashing with soap nearly eliminated microorganisms and reduced diarrhoea by 48% (Brown *et al.* 2013). Handwashing showed to be most effective when combined with water quality interventions (Crocker *et al.* 2016; Kwami *et al.* 2019), and with regular visits from promotors to reinforce behaviour change (Pickering *et al.* 2019).

A strong correlation exists between household hygiene and environmental contamination, and childhood stunting with direct effect on children under 2 years. A study in Burkina Faso found that children living in the most contaminated environments had a 30% higher risk of being stunted in comparison to their peers in the least contaminated environments (Fregonese *et al.* 2017). Geophagy, the practice of eating soil, during early childhood development and exploratory play is particularly responsible for faecal bacteria ingestion (Ngure *et al.* 2014).

Environmental contamination and increased numbers of faecal bacterial and helminths are present when animals are kept in shared spaces with children (Kaur *et al.* 2017). An estimated one-third of children under 5 years die from

exposure to pathogens in animal faeces (GBD 2015 Mortality and Causes of Death Collaborators 2016). Designated play spaces to separate children from animals successfully reduced contamination of the household environment; however, they were challenged by scepticism and reluctance to adopt changed behaviours (Reid *et al.* 2018).

The success of all hygiene interventions relied on high and sustained adherence. Cultural barriers prevented behavioural change in numerous incidences; visual assessment of water quality was the preferred method and geophagic practices were encouraged in some communities (Wirth *et al.* 2019). Evidence suggests that higher levels of formal education (Mshida *et al.* 2018) and education to promote improved hygiene behaviours improved adherence (Ejemot-Nwadiaro *et al.* 2015).

Feeding practices and nutritional interventions

Exclusive breastfeeding until 6 months has consistently shown correlation with lower stunting rates. Breastmilk provides the necessary nutrients for child growth in the early months, protects from a contaminated external environment and benefits from high adherence likely due to a preference for natural behaviours (Marugán *et al.* 2018).

Complementary feeding from 6 months ensures continued supply of adequate nutrients and increased dietary diversity (Marugán *et al.* 2018). However, weening and introducing other foods prior to 6 months was found to increase the probability of stunting, likely due to an underdeveloped digestive system and increased exposure to environmental contaminants (Mshida *et al.* 2018).

The recent SHINE and WASH Benefits Kenya trials emphasise the necessity of correct nutrition and found that nutritional interventions were as affective alone as in conjunction with WASH (Humphrey *et al.* 2019).

Combined interventions

Combinations of WASH infrastructure, educational, hygiene and nutritional interventions have been trialled to varying efficacy. As above, SHINE and WASH Benefits Kenya trials found no additional benefit from combined interventions over nutritional interventions alone (Humphrey *et al.* 2019). The findings from both conclude that more robust infrastructure is necessary to see a benefit from WASH intervention and that the unexpected results may be due to high baseline WASH conditions (Arnold *et al.* 2018; Humphrey *et al.* 2019).

Two studies concluded that the combined presence of improved water and sanitation simultaneously reduced stunting and increased the possibility of stunting reversal (Esrey *et al.* 1992; Merchant *et al.* 2003). Similarly, a third study compared various combinations of WASH, nutritional and healthcare interventions, and found that only the WASH intervention group showed significant reduction of stunting (Fenn 2012). Two papers identified that trials reporting success of infrastructural WASH interventions were commonly non-randomised; favouring intentional cohort selection and self-enrolment (Fenn 2012; Hossain *et al.* 2017). Other studies found additional counselling and specific behavioural education necessary for infrastructural interventions to be effective (Briceño *et al.* 2017; Null *et al.* 2018).

DISCUSSION

Pathways to stunting

The lack of a finite understanding of causal pathways through diarrhoea, EED and malnutrition presents challenges when designing, conducting and interpreting trials, and implementing interventions elsewhere.

The lack of a useable biomarker to determine EED is a particular problem and has resulted in trials using diarrhoea incidence as a proxy for EED presence. However, as EED is often asymptomatic, diarrhoea presence can confirm either diarrhoea alone or in combination with EED (WHO 1992). Also, given the mixed evidence of the relationship between diarrhoea and EED, it is possible that two very distinct issues are being combined complicating and possibly invalidating results (Mbuya & Humphrey 2016). Serology as an indicator of infection would provide additional information for possible EED presence; however, as EED does not as yet have known unique biomarkers, this would still not enable a conclusive diagnosis. Some studies have shown that improved sanitation reduces stunting prevalence but has no effect on diarrhoea and that studies showing a reduction

in diarrhoea incidence typically involve water or combined interventions. This suggests another link between faecal–oral transmission and stunting, and supports the argument that EED is a primary causal pathway warranting further research.

WASH infrastructure

Sanitation

Most efficacious sanitation interventions were those that most effectively interrupted the faecal–oral transmission pathway.

Access to a latrine for adult use was shown to reduce childhood stunting rates in four trials reviewed in this paper (Daniels *et al.* 1991; Esrey *et al.* 1992; Merchant *et al.* 2003; Pickering *et al.* 2015), however did not affect diarrhoea rates in young children unless combined with water interventions. Latrine access is likely to show such results because of the immediate reduction in exposure to faecal-oral pathogens from open defaecation, affecting those of all ages and specifically children under 2 years through less contaminated feeding practices.

Similarly, other trials examining sanitation interventions found solutions aimed at reducing open defaecation to adoption of any fixed-point facility to most effectively reduce stunting. Disposal of child faeces into an improved sanitation facility also showed reductions in stunting across a multiple country analysis, however found significant challenges to adherence and sustained behaviour change. It follows that to be effective, sanitation interventions must have widespread adoption else children continue to be exposed to contaminated land and water sources from a cycle of faeces contamination.

Trials commonly stressed the importance of behavioural education to achieve widespread behavioural change. Those that did not include strong educational elements, such as the SHINE trials, found a reduced effect on stunting, EED or diarrhoea prevalence.

It follows that sanitation interventions should focus on urgent provision in environments with no pre-existing facilities to reduce open defaecation and direct faecal-oral exposure. Significant investment in supportive social behavioural change programmes is justified to overcome issues of widespread use, sustained hygiene practices and cultural gender barriers.

Water availability

Piped water into the home proved to be strongly linked with a reduction in stunting rates through increased water use per capita, improved hygiene and household cleanliness, and in combination with improved sanitation. Typically, the more sophisticated the infrastructure (such as networked infrastructure with safe treatment), the greater the reduction in stunting and diarrhoea rates. However, much of this research failed to consider affordability for financially stressed households, and infeasibility of reaching such high infrastructure quality thresholds. More research regarding transitional interventions would be beneficial to find more affordable and accessible solutions in the absence of more robust infrastructure.

Of all physical interventions, water availability has proven the most closely associated with socio-economic factors. Alleviation of the time burden associated with WASH activities particularly has showed positive effects of increased time in education, increased time in employment, a reduced gender gap, increased time to maintain household cleanliness and increased time to care for and feed young children. An increase in available time directly affects children in their first 1,000 days as more time is available for childcare and feeding practices, and indirect benefits can be seen by alleviation of the degenerative intergenerational effects of the poverty cycle. Given the breadth of benefits, provision of water nearer the home to reduce the time burden of water collection should be a research priority.

Water quality

Most trials involving water quality examined the relationship with diarrhoea rather than the direct link to stunting although found positive effects as children in their early years are shown to benefit through the use of cleaner water for drinking, food preparation and household cleanliness. However, given the unconfirmed link through diarrhoea, more trials to test the direct relationship to stunting would be beneficial.

Of the trials assessing the relationship with diarrhoea, significant improvements were found using point-of-use interventions. Although Clasen *et al.* (2015) found insufficient evidence to justify water quality interventions at source, this may be overcome by exploring a combination of point-of-use interventions alongside measures to improve access and bring water nearer to the home.

Widespread feasibility of point-of-use interventions has not been explored, particularly necessary as chemical and filtration systems provided for each household are questionably uneconomical. Despite this, household treatment systems may be a suitable intermediary alongside continued research into interventions at source.

Little information is available regarding water storage and handling methods, which have high potential to contaminate water through stagnation and bacterial growth, likely negating any previous water quality treatments. Efforts to investigate appropriate storage and handling methods would, therefore, be beneficial.

Hygiene and behavioural interventions

Trials examining handwashing typically assess it in relation to diarrhoea rather than stunting and have found that handwashing reduces diarrhoea rates when practised regularly at critical times before eating and after defaecation. The provision of soap is also critical due to its ability to kill bacteria and viruses. Promising results have been observed in conjunction with water quality interventions. This suggests potential of combined interventions to incorporate handwashing facilities, improved water quality and soap, but that adherence and high adoption are critical to success. Furthermore, little evidence exists for the promotion of infant and child handwashing practices specifically and requires further research given the frequency of hand-to-mouth contact in young children.

Environmental contamination and hygiene at home have proven to be a significant contributing factor to faecal-oral pathogen exposure and stunting. Simple methods to decrease environmental contamination have proven impactful, particularly when aimed directly at young children. Measures to separate children and animals immediately remove the child from direct contact with animal faeces and is an effective, easily implementable solution.

Achieving the behavioural change required to increase handwashing practices requires continued hygiene education, necessitating interventions to target social factors. Given the mixed results of WASH interventions alone, it provides hope that WASH efficacy may be bolstered with stronger, more thorough supportive social engagement programmes.

Greater improvements in stunting rates are observed when improved hygiene behaviours are adopted on broad-scale community levels. For example, the benefits of the transition from open defaecation to fixed-point defaecation are only observed following widespread adoption; household and community environments will only remain free from animal faeces if all community members commit to separation of livestock; and change to inherent cultural beliefs will only be achieved as a collective. As mothers are not always the primary caregiver, others responsible for childcare must also maintain appropriate hygiene practices and interventions must target this demographic. There may also be possible benefit to exploring community health centres to generate social inclusion and support which has potential to increase community-wide behaviour change.

There is evidence that higher maternal and caregiver educational levels correlate with decreased stunting rates in children under 2 years; attributed to a higher baseline knowledge of suitable care practices. However, in the absence of formal education, targeted nutritional and hygiene education may overcome the immediate barriers to childcare practices. In the longer-term, higher levels of formal education will assist with improved employment opportunities and the chance to interrupt the poverty cycle.

Feeding, nutritional and combined WASH interventions

Exclusive breastfeeding until 6 months has consistently shown correlation with lower stunting rates. High adoption rates are likely due to a preference for natural behaviours free from social barriers associated with other interventions. Exclusive breastfeeding until age 6 months ensures that infants receive the required nutrients without need for complementary feeding. Where mothers or the primary

caregiver are unable to breastfeed, clean water is of even greater importance to help protect against environmental contamination for sanitary food preparation.

This study does not focus on exclusive nutritional interventions; however, the SHINE and WASH Benefits Kenya trials have both shown promising results when implemented alone. The SHINE trials found nutritional interventions were as successful alone as in combination with WASH. However, securing an adequate and varied diet is part of the larger pre-existing problem, and feasibility and sustainability of wide scale nutritional supplementation is questionable. Hence, further research into broader integrated WASH and nutritional interventions is justified through the necessity to find a more sustainable solution.

Study methodologies and limitations

Study design

The wider environment and socio-economic context have been shown to significantly affect trial results, including climatic conditions, economic instability and political volatility. Longer-term studies with larger cohorts are suggested to better account for these variables, and to also enable intergenerational monitoring to reflect social development.

Secondly, infrastructural interventions are difficult to carry out under blind trial conditions, and many variables associated with this subject are inherently unamenable to randomised controlled trials (RCTs). WASH trials are particularly vulnerable due to the sensitivity of issues at hand. Behavioural interventions are difficult to control and compare due to immeasurable consistency and reporting subjectivity. It may be beneficial to move away from blinded trials and RCTs in favour of locations and cohorts selected specifically for the situation, environment and WASH requirements.

Furthermore, evidence does not show correlation between the prevalence of stunting and number of trials carried out in each location. Conscious location selection would help target interventions and research towards the most effected populations. Notably only one trial was carried out in an urban environment, perhaps due to an assumption that food, water and sanitation are more readily available in cities. However, research would benefit from trials in urban locations, particularly amongst the urban poor and marginalised populations.

Lastly, there is often limited effort to consider or record pre-existing environmental conditions or existing facilities before implementing interventions. This is critical to enable accurate analysis, to determine the scale of change and to assess feasibility of replication elsewhere.

Cohort selection

The fundamental structure of these trials requires a continuous cohort throughout the trial period. Most studies only consider living children, despite that miscarriages and infant deaths may be attributable to the numerous primary and secondary factors discussed (Kaur *et al.* 2017).

No studies have been found including babies and children with pre-existing disabilities or illnesses. While adjusting for confounding illnesses would greatly complicate trials, it must be considered that pre-existing conditions and chronic poverty could pre-expose children to the primary biological causal factors, impact efficacy of WASH interventions or effect observed stunting rates.

Data collection methods

Most field trials comprise a combination of quantitative and qualitative data collection methods; each presenting merits and disadvantages and raising a case for studies using mixed methods. RCTs are typically considered preferable and benefit from more easily interpretable numerical data. However, numerous papers reviewed in this study fail to justify cohort or location selection, or contain uncontrolled variables preventing reliable interpretation of results.

Qualitative data collection using household surveys can achieve a deeper understanding of the issues at hand, however require a full understanding of the surrounding socio-cultural behavioural factors. Qualitative surveys must be careful of subjective reporting for social reasons, and perception bias caused by narrow data collection time frames.

Mixed method studies to benefit from numerical data for analysis and qualitative data for interpretation of environmental and contextual factors would be of greater benefit.

Lag in anthropometric measurements

The lag between onset of causes and physical stunting evident through anthropometric measurements is unknown. Similarly, there is a delay once interventions are put in place until changes in height are reflected in HAZ scores. The papers studied in this report do not discuss or justify time frames chosen, and lack of evidence suggests that these periods are not fully understood.

The lack of a full understanding of the direct causal factors of stunting is an exacerbating factor. The incubation period of EED is unknown, so that the lag between onset, visibility of symptoms (if any) and observed stunting is unknown. An enhanced understanding may also help advise potential periods for catch-up growth.

Governance and the broader supporting context

Much of the available literature examines the efficacy of WASH interventions in field settings in isolation; however, little research considers the supporting mechanism required for implementation. Policy, finance and governance alongside public engagement must be in place to support and facilitate widespread application. The broader national political and economic climate has the potential to both aid and inhibit progress as the foundation of the poverty cycle. Evidence supports that economic progression from lower-income economies (LIC) to lower-middle-income economies (LMC) is reflected in population health and stunting prevalence.

Identification of this context would assist a full interpretation of results from studies, plan an optimal cross-sectoral approach and help achieve replication elsewhere. Finding effective solutions is fundamentally required, however ensuring their feasibility at scale, equity of access and a suitable mechanism to implement, manage and maintain them is as essential.

GAP ANALYSIS AND RECOMMENDATIONS

The following gap analysis presents concise recommendations for future work informed by the former findings and discussion.

Causal pathways

A conclusive understanding of the direct biological causal pathways of stunting is necessary to validate trial results. Collaborative research in the field of health is ongoing; however, in the immediate term, interpretations of results must remain cognizant of using proxy measurables. Indirect causes are discussed but underrepresented in research despite evidence of their effect on stunting and potential as intervention points. WASH as a component of a chronic poverty trap should be more thoroughly explored, to understand its indirect effect through education and income as well as biological causes.

The presence of EED at birth and therefore onset of causes *in utero* requires further research to offer insight into pathogen transmission routes and possibly generate a shift in research towards interventions during pregnancy. Similarly, studies exploring bacteria transmission through breastmilk are also lacking. Windows of opportunity for catch-up growth are not fully investigated although the first 1,000 days are thought to be the optimal opportunity for stunting reversal. Research into this area would be beneficial in instances where proactive interventions have been unsuccessful or implemented too late.

WASH and babyWASH

More research is required to test WASH interventions targeted at children in their first 1,000 days specifically. However, research studying WASH interventions across multiple age groups have shown to be effective at reducing stunting in children under 2 years, thereby warranting research into more targeted application to this age group.

Research should focus on finding interventions that most effectively interrupt the faecal–oral transmission pathway to reduce exposure of faecal pathogens to children under 2 years. Specifically, sanitation interventions to transition from open to fixed-point defaecation and improve faecal sludge management should be further researched and prioritised; proven to have greatest immediate and widespread impact. Efforts to encourage separation of animals and children should also be increased to reduce environmental contamination as an enabler for faecal–oral pathogen transmission.

More robust and reliable water infrastructure, particularly on premises, shows greater reduction in stunting; however, unaffordability prevents access and necessitates further research of intermediate solutions. Point-of-use water quality interventions have proven effective to reduce diarrhoea rates; however, further research to explore effective interventions at source is warranted given potential for a broader sustainable impact and improved economic feasibility. Water collection and storage practices have not been explored in detail, which if unsuitable could be responsible for water contamination if inappropriately handled or stored post-treatment. There is also a lack of consideration for infrastructure operation and maintenance which must be simple, feasible and affordable to ensure sustained use. Community ownership may be beneficial to promote upkeep of facilities; however, there is little evidence of this approach. Greater personal investment, ownership of infrastructure and community-led educational programmes should be trialled as a method of simultaneously reaching many people, promoting improved childcare and hygiene practices, and encouraging community-led behaviour change.

Age appropriate interventions targeted specifically at children in their first 1,000 days should be explored further as few trials focus on these specifically. These interventions show promise; handwashing of children's hands, separation from animal faeces and exclusive breastfeeding directly affect young children themselves and should be explored as a priority.

More extensive handwashing promotion and provision of fixed handwashing facilities and soap should be explored in tandem with infrastructure provision to exploit the potential of handwashing adherence shown in trials to date. Social behaviour change and education interventions have proved a critical factor to achieve higher adherence.

The time burden of WASH activities and associated gender roles have shown strong correlation with the poverty cycle and stunting. However, no trials were found to explore this issue specifically despite the urgency warranted due to the potential scale of impact to childcare and stunting.

Nutrition and feeding practices

Trials such as SHINE found that WASH interventions did not improve efficacy of nutritional interventions alone. However, more radical and robust WASH solutions should continue to be explored in combined trials to find a more sustainable solution to widespread nutritional supplements. Initiatives to better integrate WASH interventions into nutritional programmes, in addition to trialling groups concurrently, would be beneficial.

Breastfeeding until at least 6 months should be promoted as an effective, easily implementable and natural behaviour to ensure young babies are provided with necessary and adequate nutrients in their early months. Breastfeeding interventions must be continued as an intrinsic part of stunting reduction, but supporting WASH interventions are necessary to provide an uncontaminated environment for sanitary food preparation and improved food safety.

Research methodologies

A move away from RCTs to include more varied methodologies would add value. Less reliance on RCTs and a conscious selection of locations and cohorts should be trialled to tailor interventions for each setting and achieve results which better reflect 'real world' application. Study locations should be aligned with areas of high stunting prevalence, with the aim of addressing the worst affected areas as a priority. Holistic contextual and environmental factors should also be considered in location selection and interpretation of results.

Cohort selection should consider children with existing disabilities and illnesses, to identify whether other illnesses pre-expose children to the primary biological causes of stunting. If so, there may be opportunity to address pre-existing conditions to reduce stunting.

Innovative research methodologies and radically revised data collection methods are required to find novel ways to address uncontrolled variables. Methods to reflect the sensitivity of issues discussed and discourage conformation to social pressures and desirability should be explored. Similarly, socio-cultural and behavioural studies to gain an understanding of the social context would help to more accurately interpret results. Communities need to be actively involved to ensure people are supportive and willing to adopt chosen interventions through mechanisms such as

participatory research. The use of implementation science to optimise adoption of interventions would be beneficial.

Governance

WASH research should be considered as part of a broader, multi-sectoral programme. Papers fail to consider the wider supporting mechanism, which has potential to be both a limiting and enabling factor. If explored in context, outcomes of research would offer a fuller understanding of efficacy and a more realistic assessment of feasibility.

Cross-sectoral collaboration is required to involve multiple disciplines to ensure social and behavioural science is combined with health and engineering fields for valuable varied perspectives.

CONCLUSION

This report demonstrates the complex interlinkages between direct and indirect causal pathways and stunting. It exposes the heterogeneity of findings to date, and necessity for further research into both biological and contextual influences. However, despite mixed results, it identifies many promising findings showing the ways in which WASH and babyWASH interventions can reduce child stunting.

WASH shows to be particularly effective in reducing faecal–oral pathogen transmission through interruption of the 'F' diagram, with particular success using sanitation interventions to reduce open defaecation, and water interventions to bring water nearer to the home to reduce contamination exposure points. Although not specifically targeted at children under 2 years, these interventions proved some of the most effective to reduce child stunting through the improvement of broader contamination and hygiene levels. The results show that these broader WASH interventions typically need to be in place first for more targeted babyWASH solutions to build on; sanitation must be in place for correct disposal of child faeces, water must be available to maintain hygienic feeding practices, and widespread social behavioural change is needed to improve child handwashing, play and feeding behaviours.

For future research, trial methodologies must be revisited to more fully consider broader social and contextual factors, and apply mixed quantitative and qualitative data collection methods. WASH must be considered as part of a broader interdisciplinary programme to address the impact of governance and the wider economic and political climate. Regional, national and international support is also critical to address the underlying socio-economic factors responsible for intergenerational stunting. Finally, and critically, future studies must explore WASH and babyWASH as a broader network of research, drawing on expertise across multiple social science, medical and engineering fields.

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DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories.

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