WASH and child health outcomes: comprehensive impact evaluation

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1. Executive summary

Water, sanitation and hygiene (WASH) are widely recognized as important interventions against global child health burden. Primarily, WASH interventions aim to interrupt fecal pathogen transmission in order to prevent intestinal infections. More recently, there has been a growing recognition of the indirect pathways through which WASH prevents other child health conditions, such as malnutrition and morbidities from other infectious diseases. In turn, it has been suggested that the integration of WASH with preventive child health interventions may attain greater efficiency in preventing a larger set of child health burdens.

This report presents a map of the complex link between WASH and various child health outcomes. The impact of WASH interventions on children's diarrhea, pneumonia and growth are quantified using Comparative Risk Assessment method, a widely used approach in Lancet Global Burden of Disease studies (Ezzati et al. 2002). The impact of integrating WASH with breastfeeding promotion, zinc supplementation and immunization against rotavirus, pneumococcal, and *Hib* is also assessed. To quantify the impact of WASH and WASH-integration, the proportion of global morbidities and mortalities from diarrhea and pneumonia attributable to the lack of the interventions are determined. The joint impact of integrated interventions is determined as the product of the effects.

In summary, this report finds the following potential impact of WASH and WASH- integrated interventions on global child health burden from diarrhea and pneumonia:

- 47% of morbidities and 26% of mortalities may be prevented with WASH interventions.
- Breastfeeding promotion, zinc supplementation and immunization interventions can individually reduce up to 22% of morbidities and 31% of mortalities.
- Integration of WASH, rotavirus vaccination and nutritional interventions (breastfeeding or zinc) can reduce up to 63% of morbidities and 49% of mortalities.
- Breastfeeding integrated with WASH leads to 3 times and 1.5 times greater reduction in morbidities and mortalities than breastfeeding alone.
- Zinc supplementation integrated with water quality improvement leads to 2.3 and 3.7 times greater reduction in morbidities and mortalities than zinc supplementation alone.
- Rotavirus immunization integrated with hygiene promotion leads to 1.9 and 4.9 times greater reduction in morbidities and mortalities than rotavirus immunization alone.
- Rotavirus immunization integrated with sanitation leads to 1.3 and 1.8 times greater reduction in morbidities and mortalities than rotavirus immunization alone.
- Pneumococcal and *Hib* immunization × hygiene promotion leads to 23.6 and 4.4 times greater reduction in morbidities and mortalities than pneumococcal and *Hib* immunization alone.

The existing evidence on the effect of WASH on children's growth is not in agreement, and thus was not investigated further.

The findings suggest that the integration of WASH with other preventive child health interventions can lead to greater health benefits, and may return higher health gain per investment, particularly when there is a synergetic cost reduction from integrating the interventions.

2. Introduction

2.1 Rationale

Improved water, sanitation and hygiene (WASH) can reduce child health burden via multiple pathways, both directly and indirectly. Implementation of WASH in conjunction with other child health interventions may simultaneously address multiple pathways, thereby yielding greater health benefits. Yet, there is a lack of comprehensive overview on the potential impact of WASH and WASH-integrated interventions.

2.2 Objectives

The main purpose of this report is to provide WaterAid with a comprehensive overview of the impact of water, sanitation, and hygiene (WASH) interventions on various child health outcomes, and to estimate the potential impact of integrating WASH interventions with other preventive interventions for child health. The specific objectives are:

1. To conceptualise the plausible impact pathways of WASH and WASH-integrated interventions on various child health outcomes
2. To quantify the impact of WASH on various child health outcomes
3. To estimate the potential impact of WASH-integrated interventions on child health outcomes

2.3 Scope

This report conceptualized the plausible link between WASH and a broad set of under-five children's health outcomes. The potential impact of WASH and WASH-integrated interventions were quantified, with specific focus on children's morbidities and mortalities from diarrhea and pneumonia, as well as children's growth. The key interventions against these health outcomes were considered, as identified in the key global child health literature (Bhutta et al. 2013) (See Table A 1 for the complete list). The health outcomes and interventions examined in this report are shown in Table 1.

Table 1. The scope of child health outcomes and preventive interventions assessed

Health outcomes	Diarrhea (morbidities and mortalities)
	Pneumonia (morbidities and mortalities)
	Growth (height, cognitive abilities)
Interventions	WASH
	Breastfeeding
	Zinc supplementation
	Immunization (rotavirus against diarrhea, Pneumococcal and *Hib* against pneumonia)

3. Conceptualization of WASH and child health outcomes

3.1 Overview

WASH interventions promote clean water, improved sanitation, and hygiene, in order to interrupt pathogen transmissions, and thereby reduce the overall fecal pathogen dose that children are exposed to. By doing so, WASH interventions not only prevent infection by fecal pathogens, but also reduces other child health outcomes, such as malnutrition and infectious diseases via multiple biological pathways.

In this section, the theoretical causal pathways between child health interventions and child health outcomes are presented. Focus is placed on the link between WASH and various health outcomes, and the potential interaction between WASH and other child health interventions.

3.2 Causal chain of child health events

Figure 1 maps the chain of events that lead to child health outcomes, and the potential interventions that may be implemented to interrupt the events.

3.2.1 WASH and pathogen exposure

WASH can directly reduce the dose of disease-causing pathogen that children are exposed to, thereby reducing the likelihood of infection. The traditional focus of WASH interventions has been on improved water quality, sanitation infrastructure and hand hygiene, but there has been an increased interest in broadening the boundary of WASH by including the downstream processing of wastewater and fecal sludge, and ensuring sanitary surroundings for infants by baby WASH, as elaborated further in Section 5.3. The health outcome from exposure to pathogens depend on the child's immunity.

3.2.2 WASH and undernutrition

Poor WASH conditions can lead to undernutrition via two main biological mechanisms: by gastrointestinal infection that lead to nutrient malabsorption, and by causing other illnesses that lead to low food intake and hypermetabolism.

The ingestion of fecal pathogens and helminths due to poor WASH can cause gastrointestinal infections that impair the gut's ability to absorb nutrients via repeated bouts of diarrhea (Checkley et al. 2008), and tropical or environmental enteropathy (Humphrey 2009). Environmental enteropathy, or environmental enteric dysfunction (EED) as it is more recently known, is a chronic disorder of the small intestine that occurs due to the ingestion of fecal pathogens, that can interrupt the absorption of nutrients (Humphrey 2009). Furthermore, children that experience illness tend to not only consume less food, but use excessive amount of energy and protein as part of the immune response.

In addition to the metabolic links, inaccessible water sources can cause additional financial burden on households (e.g., water purchase, travel time to access water), that may drain funds required for adequate diet and time caring for children.

3.2.3 WASH and immunity

Inadequate WASH can lead to impaired immune system by causing malnutrition, which is the primary cause of immune system deficiency. In severely malnourished children, both the acquired immunity (from vaccination or placenta) and host defense mechanism are negatively affected. Such impairment of immunity renders children more susceptible to further infections, thereby causing a vicious cycle between infection and malnutrition.

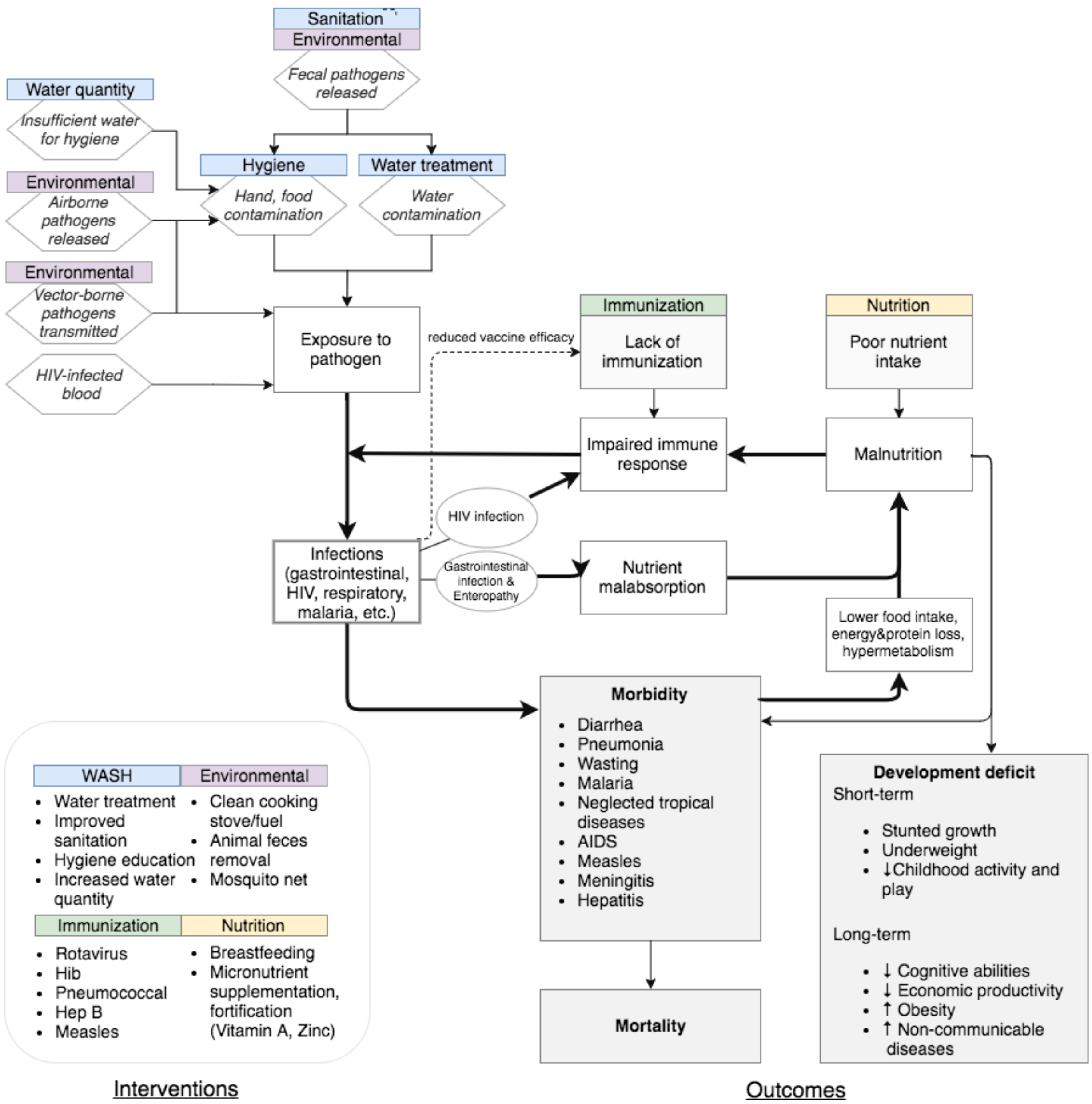

Figure 1. Health event causal pathways and role of health interventions (Bold arrow: infection-malnutrition cycle)

4. Impact of WASH and WASH-integrated interventions

4.1 Method overview

4.1.1 Health outcome and interventions considered

The impact of WASH and a set of WASH-integrated interventions on child health were determined. The health outcomes considered were the morbidities and mortalities from diarrhea and pneumonia, as well as a growth-related outcome (height-for-age z score (HAZ)). The health burden from diarrhea and pneumonia were of primary interest as they pose the largest threat on global child mortality, each causing 15% and 23% of global post-neonatal (1-59 months) mortality. The child health interventions considered were selected from a set of recommended interventions against children's diarrhea, pneumonia and stunted growth from a key Lancet study (Bhutta et al. 2013). The complete list of recommended interventions is shown in Appendix 1.

4.1.2 Approach and assumptions

To estimate the impact of WASH and other health interventions, Comparative Risk Assessment method was used (Ezzati et al. 2002). Primarily used to assess the global health burden from risk factors, comparative risk assessment method has been widely used in the global burden of disease (GBD) studies (Ezzati et al. 2002, 2003; Black et al. 2013).

In essence, the method considers a risk factor and an health outcome, and determines the proportion of current morbidity and mortality that would be reduced when the risk factor is diminished by an intervention (i.e., intervention reaches 100% coverage from the current status). The proportional reduction in health burden by the interventions is quantified as PAF (population attributable fraction) (Ezzati et al. 2002). The joint impact of WASH-integrated interventions was determined as the product of individual PAFs, following the approach used in GBD studies.

The assumptions made in determining PAF are as follows:

1. Intervention coverage is increased from the current state (Table A 4 in Appendix 4) to 100% global coverage.
2. The joint impact of multiple interventions is estimated as the product of proportional health burden reduction.
3. The relative effect (relative risk) of WASH intervention on mortality was approximated to be the same as that on morbidity, as assumed in previous burden of disease studies (Lim et al. 2012; Prüss-Ustün et al. 2014).

The impact WASH and WASH-integrated interventions were estimated by the following three steps.

1. Input data acquisition

The following data was acquired from the literature:

- Relative risk of interventions (Table 2)
- Global child health burden (i.e., number of morbidities and deaths, Table A 3 in Appendix 3)
- Current coverage of interventions (e.g. 70% with sanitation, Table A 4 in Appendix 4).

2. Impact quantification of individual intervention by population attributable fraction

   Using the obtained information, the % reduction in the global child morbidities and mortalities by WASH were estimated by calculating the population attributable fraction (see Appendix 3).

3. Joint impact quantification of interventions by population attributable fraction

   For WASH-integrated interventions, the joint impacts were determined by finding the product of the individual intervention effects. The details of the approach are presented in Appendix 3.

4.2 Impact on morbidities and mortalities

4.2.1 Existing evidence on the effect of WASH & WASH-integrated interventions and global child health burden

Table 2 describes the key interventions considered and their effect sizes on diarrhea and pneumonia, as reported in the prior literature. The health effect is quantified as effect size in relative risk (RR), where RR less than 1 means less risk. The majority of the data was obtained from prior systematic reviews on the interventions. The only exception was for the effect of rotavirus immunization, which was obtained from a single randomized controlled trial due to the lack of a systematic review on the topic; there has been one systematic review on the effect of rotavirus vaccine, but the review was specific to rotavirus morbidity and mortality outcomes, rather than all-cause diarrhea.

Table 2. Effect size (relative risk, RR) of interventions on child health outcomes

Outcome/ Interventions	Effect size (RR (95%CI)[a]) Morbidity	Mortality	Intervention description	Reference
Diarrhea				
Water	0.48 (0.38-0.59)	-[b]	Point-of use filtration	(Clasen et al. 2014)
Sanitation[c]	0.72 (0.59-0.88)	-[b]	Sanitation facility, sewer connection	(Wolf et al. 2014)
Hygiene	0.66 (0.43-0.99)	-[b]	Handwashing promotion	(Ejemot-Nwadiaro et al. 2015)

Breastfeeding (<6 months)	0.6 (0.36-0.97)	0.22 (0.09-0.55)	Exclusive vs. partial breastfeeding	(Lamberti et al. 2011; Walker et al. 2013)
Breastfeeding (6-23 months)	0.76 (0.61-0.94)	0.46 (0.24-0.88)	Any vs. no breastfeeding	(Lamberti et al. 2011; Walker et al. 2013)
Zinc supplementation	0.83 (0.83-0.91)	0.83 (0.63-1)	Zinc deficiency	(Yakoob et al. 2011)
Immunization	0.70	0.65	Live, oral rotavirus vaccine	(Madhi et al. 2010)
Pneumonia				
Hygiene	0.84 (0.79-0.89)	-[b]	Handwashing	(Jefferson et al. 2008)
Breastfeeding (<6 months)	0.56 (0.4-0.78)	0.40 (0.17-0.97)	Exclusive vs. partial breastfeeding	(Lamberti et al. 2013)
Breastfeeding (6-23 months)	0.85 (0.27-2.7)	0.52 (0.21-1.27)	Any vs. no breastfeeding	(Lamberti et al. 2013)
Zinc supplementation	0.83 (0.71-0.83)	0.85 (0.9-1.54)	Zinc deficiency	(Yakoob et al. 2011)
Immunization (Pneumococcal)	0.89 (0.81-0.98)	0.82 (0.66-2.27)	Pneumococcal vaccine	(Theodoratou et al. 2010)
Immunization (Hib)	0.94 (0.89-0.99)	0.93 (0.93-1.23)	Hib vaccine	(Theodoratou et al. 2010)

a. Relative risk (RR) = (risk of illness without intervention/ risk of illness with intervention); RR<1 indicates less risk with the intervention.
b. Relative risk of morbidity is used as a proxy for the relative risk of mortality, due to the lack of rigorous evidence; the estimated health burden reduction is likely an overestimate.
c. May be biased, see Appendix 2 for recent randomized controlled trial results

4.2.2 WASH interventions on morbidities and mortalities

The estimated impact of WASH on under-five diarrhea and pneumonia are presented in Table 3. Approximately 25% of diarrheal burden is attributable to the lack of safe drinking water or hand hygiene, followed by 11% attributable to poor access to sanitation. Hand hygiene was correlated with 12% reduction in pneumonia, while the association of water and sanitation with pneumonia were assumed to be negligible. It is estimated that the joint provision of water, sanitation, and hygiene may save 47% of under-five morbidity episodes and 26% of under-five deaths from diarrhea and pneumonia globally.

Table 3. Disease burden averted by WASH*

	# Morbidity episodes averted (millions)	# Lives saved
*Water**		
Diarrhea	2,289 (24%)	119,266 (24%)
Pneumonia	-	-
Sum	**2,289 (21%)**	**119,266 (8%)**
*Sanitation**		

Diarrhea	1,060 (11%)	55,213 (11%)
Pneumonia	-	-
Sum	**1,060 (10%)**	**55,213 (4%)**
*Hygiene**		
Diarrhea	2,617 (27%)	136,341 (27%)
Pneumonia	147 (12%)	60,768 (12%)
Sum	**3,783 (35%)**	**197,108 (14%)**
*WASH joint**		
Diarrhea	4,866 (51%)	253,544 (51%)
Pneumonia	147 (12%)	112,064 (12%)
Sum	**5,013 (47%)**	**365,608 (26%)**

a. Assumed relative risk of mortality= relative risk of morbidity, due to lack of rigorous evidence.
b. Similar study has been done by Pruss-Ustun, but with data preceding 2013; see Appendix 4.

4.2.3 WASH-integrated interventions on morbidities and mortalities

The potential impacts of WASH-integrated interventions on under-five diarrhea and pneumonia burden (morbidities and mortalities) are shown in Table 4 and Table 5. All possible combinations of child health interventions (breastfeeding, zinc supplementation, immunization) and water, sanitation, hygiene, or joint WASH intervention were considered. In addition, the potential impact of three-fold integration of WASH with both rotavirus vaccine and nutrition interventions were considered. The impact estimated for each health outcome, i.e., diarrhea and pneumonia, are presented in Appendix 5.

It was estimated that approximately 1 to 22% of morbidities from diarrhea and pneumonia would be prevented with breastfeeding, zinc supplementation and immunization. Integrating these interventions with other WASH interventions increased the reduction by additional 10 to 50%. It is worth noting that the immunization against pneumococcal disease and *Hib* is linked with only 1% reduction in morbidity, unless integrated with WASH interventions. The largest reduction in morbidities was estimated with rotavirus immunization and joint WASH interventions (56%).

Table 5 shows the estimated reduction in mortalities by WASH and WASH-integrated interventions. Overall, zinc supplementation and immunization interventions were linked with under 7% reduction in mortalities; however, when integrated with hygiene promotion or joint WASH interventions, over 20% reduction in mortalities were estimated. In addition to joint WASH, integration of interventions with hygiene promotion showed strong potential for a large impact, with estimated reduction ranging from 28% to 42% of morbidities, and 20 to 39% of mortalities. Given the relatively low cost of hygiene promotion compared to other infrastructural interventions for drinking water and sanitation (Sijbesma and Christoffers 2009), integration of hygiene promotion with other health interventions is likely to be the most cost-effective option.

Table 4. Under-five illnesses averted by WASH integrated interventions*

	Number of illnesses averted (millions) (% global under-five diarrhea and pneumonia morbidities averted)				
	Individual intervention	W-integrated	S-integrated	H-integrated	WASH-integrated
Breastfeeding	1,552 (14%)	3,517 (33%)	2,462 (23%)	3,921 (36%)	5,853 (54%)
Zinc supplementation	1,535 (14%)	3,498 (32%)	2,444 (23%)	3,905 (36%)	5,834 (54%)
Diarrhea immunization[a]	2,363 (22%)	4,087 (38%)	3,161 (29%)	4,481 (42%)	6,028 (56%)
Pneumonia immunization[b]	128 (1%)	2,417 (22%)	1,188 (11%)	3,023 (28%)	5,272 (49%)
Breastfeeding-Rotavirus-WASH	-	-	-	-	6,830 (61%)
Zinc-Rotavirus-WASH	-	-	-	-	4,301 (63%)

* W, S, H, WASH: Water, sanitation, hygiene, water sanitation & hygiene, respectively
a. rotavirus
b. pneumococcal, and *Hib*

Table 5. Under-five deaths averted by WASH integrated interventions*,**

	Number of mortalities averted (%global under-five diarrhea and pneumonia mortalities averted)				
	Individual intervention	W-integrated	S-integrated	H-integrated	WASH-integrated
Breastfeeding	444,625 (31%)	487,591 (34%)	464,516 (33%)	552,217 (39%)	686,725 (48%)
Zinc supplementation	43,202 (3%)	158,545 (11%)	96,599 (7%)	283,858 (20%)	397,208 (28%)
Diarrhea vaccine[a]	59,191 (4%)	164,306 (12%)	107,853 (8%)	291,419 (21%)	394,716 (28%)
Pneumonia vaccine[b]	101,934 (7%)	221,199 (16%)	157,147 (11%)	449,985 (32%)	567,189 (40%)
Breastfeeding-Rotavirus-WASH	-	-	-	-	697,212 (49%)
Zinc-Rotavirus-WASH	-	-	-	-	425,359 (30%)

* W, S, H, WASH: Water, sanitation, hygiene, water sanitation & hygiene, respectively
**Assumed relative risk of mortality= relative risk of morbidity, due to lack of rigorous evidence.
a. rotavirus
b. pneumococcal, and *Hib*

4.3 Impact on child growth

4.3.1 WASH interventions on child growth

Despite the theoretical understanding that WASH can have an important impact on children's growth, prior studies have shown mixed results.

The evidence on the effect of child health interventions on children's height-for-age z score are summarized in Table 6. Height-for-age z scores are used to monitor growth, whether growth is considered stunted when the height-for-age z score is less than -2. While early childhood stunting has been linked with long-term cognitive deficits, there is currently no direct study that directly assessed the effect of WASH on cognitive abilities.

The key literature on the effect of WASH on growth are summarized in Table 6. The systematic review by Dangour et al. (2013) assessed the impact of drinking water disinfection and hygiene promotion on growth. The review found that drinking water disinfection and hygiene is positively correlated with children's growth, but not in statistically meaningful manner.

The effect of sanitation on children's growth have mixed evidence. The most recent systematic review on sanitation by Freeman et al. (Freeman et al. 2017), as shown in Table 6, found positive but statistically insignificant effect of sanitation on child's height-for-age z score. Among the two most rigorous sanitation randomized controlled trials (RCTs) included in the review (see Appendix 2)., (Clasen et al. 2014; Pickering et al. 2015) only one trial found significant effect on height-for-age (Pickering et al. 2015), but the other trial did not (Clasen et al. 2014). The difference between the two trials by Clasen et al. (2014) and Pickering et al. (2015) may be partly explained by factors such as the difference in study settings (India vs. Mali), baseline risk of illness.

Table 6. Effect of WASH on child growth (Height-for-age z score)

Intervention	Effect size measure	Effect size (Prevalence ratio)*	Study characteristics	Reference
Water & Hygiene	MD	0.08 (0.00 - 0.16)	7 RCTs	(Dangour Alan et al. 2013)
Sanitation	MD	0.08 (-0.00 – 0.16)	10 RCTs	(Freeman et al. 2017)
Sanitation#	PR	-0.04(-0.24 - 0.16)	RCT	(Clasen et al. 2014)
Sanitation#	PR	0.17 (0.04 - 0.31)*	RCT	(Pickering et al. 2015)

a. MD: mean difference, PR: prevalence ratio. MD and PR > 0 indicates positive effect on growth; # select rigorous RCTs with high sanitation uptake level;* statistically significant ($p<0.05$)

4.3.2 Other interventions on child growth

There are mixed findings on the effect of zinc supplementation on children's growth as well. A systematic review by Das et al. (2013) found positive a growth outcome with zinc supplement, but the finding was later contradicted by a systematic review by Stammers at al (2015). When measuring children's growth by the prevalence of stunting, Lassi et al. (2003) found a protective effect of sanitation and complementary feeding. Lastly, Giugiliani et al. (2015) found a small reduction in body-mass index in children (6 months old), whose mothers received breastfeeding promotion, and insignificant change in children's weight and length (Giugliani et al. 2015).

Table 7. Effect of zinc supplementation, complementary feeding and breastfeeding on children's growth

Growth measure/ Intervention	Effect size measure	Effect size	Study characteristics	Reference
Height-for-age z score				
Zinc supplementation	MD	0.52 (0.01 - 1.04)*	10 RCTs & quasi-experimental	(Das et al. 2013)
Zinc supplementation	MD	0.04(-0.13 - 0.22)	9 RCTs	(Stammers et al. 2015)
Stunting				
Appropriate complementary feeding	RR	0.68 (0.60 - 0.75)	16 RCTs & quasi-experimental	(Lassi et al. 2013)
Body-mass index (BMI)				
Breastfeeding promotion to mothers	Z-score	-0.06 (-0.12 – 0)	17 RCTs & quasi-experimental	(Giugliani et al. 2015)

a. MD: mean difference; PR: prevalence ratio; * statistically significant (p<0.05)

The existing evidence on the effect of WASH and zinc supplementation on child growth indicate that WASH and zinc supplementation are correlated with children's growth in a generally positive direction, but not in a meaningful, statistically significant way. Complementary feeding can reduce stunting by 32%, but integration of feeding interventions with WASH requires additional evidence to justify, based on the weak evidence of the effect of WASH on child growth.

4.4 Implications of WASH-integration in preventive child health interventions

As shown in Section 4.2., the integration of WASH with child health interventions can have synergetic effects on diarrhea and pneumonia burden. The current shortage of strong evidence on the effect of WASH on children's growth render it difficult to quantify the potential impact of WASH-integrated interventions on children's growth, though biologically plausible.

By integrating with WASH, breastfeeding, zinc supplementation, and immunization interventions can achieve additional reduction in morbidities and mortalities as shown in Table 8. For instance, the integration of breastfeeding with water quality improvement may reduce 2.3 times more morbidities than breastfeeding alone. Likewise, integration of rotavirus vaccination with hygiene may lead to 4.9 times more lives saved than rotavirus vaccination alone.

Table 8. Relative morbidity and mortality reduction rate (sum of diarrhea and pneumonia) compared to non-integrated intervention*

	Integrated interventions			
Outcome/ Interventions	Water	Sanitation	Hygiene	WASH
Morbidities				
Breastfeeding	2.3	1.6	2.5	3.0

Zinc	2.3	1.6	2.5	3.8
Diarrhea immunization (rotavirus)	1.7	1.3	1.9	2.6
Pneumonia immunization (pneumococcal, Hib)	18.9	9.3	23.6	41.3
Mortalities				
Breastfeeding	1.1	1.0	1.2	1.5
Zinc	3.7	2.2	6.6	9.2
Diarrhea immunization (rotavirus)	2.8	1.8	4.9	6.7
Pneumonia immunization (pneumococcal, Hib)	2.2	1.5	4.4	5.6

* e.g. Water-integrated breastfeeding intervention reduces 2.3 times more morbidities than breastfeeding interventions alone.

In addition, integrated interventions may benefit from the synergetic reduction in the overall logistical complexity, compared to single interventions that are implemented individually. Such benefit may lead to a boost in the cost-effectiveness of the integrated interventions, and yield higher health gain from investments than independent interventions. However, there is currently a lack of resources to assess this aspect.

5. Other child health interventions with weak evidence

As shown in Figure 1, there are many other child health interventions that can theoretically yield greater benefit when integrated with WASH, but currently lack conclusive evidence. In this section, the existing evidence of the effect of other potential interventions and risk factors are summarized. As listed in Table 9, the potential interventions and risk factors considered are measles vaccine, vitamin A supplementation, clean fuel cooking stove. food contamination, animal feces ingestion and atmospheric air pollution.

Table 9. Plausible interventions and risk factors in prevention of child health burden

Interventions	Potential outcomes	Findings	Reference
Not effective or inconclusive evidence			
Measles vaccine	Pneumonia	Pneumonia as a complication following measles infection occurs in 2–27% of children in community-based studies and in 16–77% of hospitalized children	(Duke and Mgone 2003)
		Measles vaccination is 85% effective for prevention of measles in children younger than 1 year.	(Sudfeld, Navar, and Halsey 2010)
Vitamin A supplementation	Lower respiratory tract illness	No effect (RR=1.14 (0.95 to 1.37) based on meta-analyses of 8 trials	(Chen et al. 2011)
Cooking stoves (RCTs)	Pneumonia, respiratory illness	No effect, Cleaner burning stove vs. biomass-fuel stoves on pneumonia (incidence rate ratio=1.01 (95% CI 0.91–1.13) in <5 children in rural Malawi	(Mortimer et al. 2017)
		Non-significant reduction, Plancha stove vs. open fire on incidence of pneumonia (RR= 0.84 (95% CI 0.63–1.13); p=0·26) in <19months old children in Guatemala	(Smith et al. 2011)
		Significant reduction, Patsari stove vs. open fire on respiratory symptoms (Rate ratio = 0.29 (95%CI=0.11–0.77) for wheeze) in women in Mexico	(Romieu et al. 2009)
Biomass fuel (observational studies systematic review)	Pneumonia, respiratory illness	Significant association, using biomass fuel (vs. cleaner fuels like kerosene, LPG, etc.) with increased acute respiratory illness (odds ratio (~relative risk) =3.53, 95% CI=1.94-6.43)	(Po, FitzGerald, and Carlsten 2011)
No epidemiological/experimental evidence, but biologically plausible			
Animal feces and soil ingestion	Diarrhea, stunting	Ingestion of animal faeces and contaminated soil by children was observed in a 23-household observational study	(Ngure et al. 2013)

		Pathogenic bacteria found in household soil samples	(Simango 2006; Pickering et al. 2012)
Mycotoxins food contamination	Stunting	Children who were stunted or underweight had 30–40% higher mean aflatoxin–albumin levels.	(Gong et al. 2002)
		A strong negative correlation between aflatoxin–albumin level and height increase was found over 8 months follow-up	(Gong et al. 2003)
Air pollution	Diarrhea	Evidence is lacking, but there's a plausible biological mechanism that air pollutants directly compromise epithelial cells in intestine leading to higher risk of infection, alter immune response, and disrupt gut microbiota	(Beamish, Osornio-Vargas, and Wine 2011)

5.1 Interventions with inconclusive evidence

Measles vaccine, Vitamin A supplementation and clean cooking stoves for indoor air pollution reduction may reduce the burden of pneumonia. However, there is inconclusive evidence that these interventions lead to measurable health benefits.

5.1.1 Measles vaccination and pneumonia

It has been reported that up to 77% of measles patients experience pneumonia as a complication; thus, the control of measles by vaccination has important implications for the reduction of pneumonia (Table 9). Consequently, the integration of measles vaccination with hygiene promotion has a high potential of reducing the cases of measles, as well as pneumonia.

5.1.2 Vitamin A and respiratory illness

Vitamin A is known to improve immunity and benefit the development of epithelium mucosae in the intestinal and respiratory tract, thereby reducing the risk of diarrhea and respiratory illness. The existing evidence reported in the previous systematic reviews shows that while vitamin A is effective in reducing diarrheal morbidity (Mayo-Wilson 2011), it may not have an measurable impact on pneumonia. A summary of eight vitamin A supplementation trials showed that vitamin A does not significantly reduce the risk of lower respiratory tract illness (Chen et al. 2011). Of the eight trials assessed in the review, vitamin A supplementation was associated increased symptoms of respiratory illness in two studies, and higher incidence of acute lower respiratory tract infection in one study. It is hypothesized that vitamin A supplementation to children with sufficient stores of vitamin A may temporally depress immune responses (Grotto et al. 2003), but experimental evidence is lacking. Thus, based on the existing evidence, the integration of vitamin A supplementation with WASH is not expected to have any synergetic effect on pneumonia.

5.1.3 Improved cooking stoves/ clean fuels and respiratory illness

Reduction of indoor air pollution with and improved cooking stoves and clean fuel has been linked with reduction in children's respiratory illnesses. Improved in-house cooking stoves vent the smoke to the outdoor environment, thereby reducing the indoor air pollution. Several RCTs have been conducted to test the effect of such cooking stoves, and of the RCTs, two have reported that improved stoves do not have any effect on children's pneumonia, while one RCT reported significant effect on women's respiratory symptoms.

Numerous observational studies have assessed the relationship between the use of biomass fuel and risk of respiratory illnesses, as reviewed by Po et al. (2011). Upon summarizing previous studies, the review found that increased risk of respiratory illness is significantly associated with the use of biomass fuel with an odds ratio of 3.53 (95% CI=1.94-6.43), or roughly 3.5 times higher likelihood of illness. However, the studies are observational in design, and are subject to confounding by other relevant factors such as the household wealth and children's nutritional status.

5.2 Plausible risk factors that lack epidemiological evidence

5.2.1 Animal feces and diarrhea

The ingestion of animal feces and soil is increasingly recognized as an important risk factor for diarrhea. There has been reports of children's ingestion of animal feces and soil, that may be contaminated with diarrhea-causing fecal pathogens. As a response, an intervention approach termed 'baby WASH' is gaining interest, that specifically target fecal-oral transmission pathways that can affect infants, such as soil, drinking water, and hands. Although plausibly impactful, there has not been a conclusive evidence on the effect of removing animal feces from the surroundings as of yet. Nonetheless, removal of animal feces has a strong potential for synergetic impact when integrated with WASH interventions, based on the likely protective effect, as well as the practical logistics for integration with community-based WASH programs like community-led total sanitation or hygiene promotions.

5.2.2 Mycotoxin food contamination and growth stunting

The risk of children's stunted growth has been associated with contamination of food staples with aflatoxins and fumonisins (FB) in a few observational studies. Aflatoxins and fumonisins (FB) are toxins that frequently contaminate maize, cereals, groundnuts and tree nuts. In parts of the world where these food items are dietary stables, such contamination translates to a high-level chronic exposure. The exposure to mycotoxins have been negatively correlated with children's growth in observational studies; however, the causal pathways have not been explicitly identified. Further research on the plausible pathways of the effect of mycotoxin on growth, and the effect of the mycotoxin contamination prevention by improved food storage conditions, are needed to gauge the importance of integration of WASH with food protection.

5.2.3 Air pollution and diarrhea

Besides respiratory illness, air pollution has been linked to gastrointestinal infection as well. It has been suggested that the exposure of the bowel to air pollutants may negatively affect epithelial cell developments and cause inflammation (Beamish, Osornio-Vargas, and Wine 2011). Air pollutants would enter the bowel via food, water, and clearance of particulate matter from the lungs. To date, there is no conclusive evidence that supports this hypothetical biological mechanism; however, this biological plausibility suggests that prevention of indoor air pollution may have additional protective impact on children's health.

6. Summary of findings

In this report, the complex linkage between WASH and child health outcomes were conceptualized, and the impact of WASH on key child health outcomes, namely diarrhea, pneumonia, and children's growth, was quantified. The potential impact of integrating WASH with other preventive child health interventions was explored, while considering the joint impact of WASH with breastfeeding, zinc supplementation and immunization against rotavirus, S. pneumoniae, and *Hib*.

It was found that, globally, 47% of morbidities and 26% of mortalities from diarrhea and pneumonia may be prevented with WASH. In comparison, breastfeeding, zinc supplementation, and immunization were correlated with 1-20% and 3-30% reduction in morbidities and mortalities, respectively. Integration of WASH with both rotavirus vaccination and nutritional interventions (breastfeeding or zinc supplementation) were correlated with up to 63% reduction of morbidities and 49% reduction of mortalities. There was weak evidence on the impact of WASH on children's growth.

Highlights of the estimated health gain from integrating WASH with breastfeeding, zinc supplementation, and immunization interventions were as follows:

- Breastfeeding × WASH leads to 3 times and 1.5 times greater reduction in morbidities and mortalities than breastfeeding alone.
- Zinc supplementation × water quality improvement leads to 2.3 and 3.7 times greater reduction in morbidities and mortalities than zinc supplementation alone.
- Rotavirus immunization × hygiene promotion leads to 1.9 and 4.9 times greater reduction in morbidities and mortalities than rotavirus immunization alone.
- Rotavirus immunization × sanitation leads to 1.3 and 1.8 times greater reduction in morbidities and mortalities than rotavirus immunization alone.
- Pneumococcal and *Hib* immunization × hygiene promotion leads to 23.6 and 4.4 times greater reduction in morbidities and mortalities than pneumococcal and *Hib* immunization alone.
- Due to the lack of strong evidence on the effect of WASH on children's growth, the impact of WASH-integrated interventions on child growth was not quantified.

Other interventions that can potentially work in synergy with WASH include measles vaccination and vitamin A supplementation, though evidence suggests that vitamin A may reduce diarrheal disease burden, but not pneumonia. Further research is needed to confirm the effectiveness of clean cooking stoves, removal of children's feces and improved food storage, prior to considering joint implementation with WASH.

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Appendix 1. Key preventive interventions for child health

Table A 1. Key child health interventions (adapted from Bhutta et al. 2013)

Outcome	Key interventions
Diarrhea	WASH*#
	Breastfeeding*#
	Preventive zinc supplementation*#
	Rotavirus vaccine#
	Cholera vaccine
Pneumonia	Hygiene*
	Breastfeeding*
	Preventive zinc supplementation*
	Pneumococcal conjugate vaccine#
	Hemophilius Influenzae type b (Hib) vaccine #
	Measles vaccine
Growth deficit	WASH*
	Breastfeeding*
	Preventive zinc supplementation*
	Safe complementary feeding#
	Iron, multiple micronutrient, vitamin A supplementation
	Maternal nutrition (micronutrient and energy protein supplementations)
	Neonate nutrition intervention (delayed cord clamping, vitamin K and A, kangaroo mother care)

Appendix 2. Summary of recent sanitation randomized controlled trials

It is noted that the effect of sanitation on diarrhea cited in Table 2 may be biased. The reported effect is an summary estimate from studies with study design limitations, e.g. not randomly assigning interventions, that can skew the effect estimate. In addition, more recent and rigorous studies on sanitation (Clasen et al. 2014; Cameron, Shah, and Olivia 2013; Patil, Arnold, and Salvatore 2014; Briceno, Coville, and Martinez 2015; Pickering et al. 2015) have reported contradictory findings, where access to household sanitation does not affect one's risk of diarrhea. The null finding may have been due to insufficient coverage of sanitation at community level, but conclusive evidence is not available yet.

Table A 2. Summary of recent randomized controlled trials of sanitation

Reference	Sanitation coverage change	Effect on diarrheal morbidity	Effect on growth (height-for-age z score)
Cameron 2013	60 to 64%	Relative risk 0.3 (4.6% morbidity prevalence reduced to 1.3%)	No effect
Hammer and Spears 2013	8.2% increase	N/A	Mean difference= 0.3 to 0.4(0.04 - 0.61)
Patil 2014	22 to 41%	No effect	No effect
Clasen 2014	9 to 63%	No effect	No effect
Briceno 2015	57 to 65%	No effect	No effect
Pickering 2015	35 to 65%	No effect	PR=0.17 (0.04 - 0.31)

Appendix 3. Impact quantification methodologies

The proportion of global morbidities and mortalities that are attributable to the lack of the interventions (population attributable fraction (PAF), %) were determined, as further explained in the following sections. The input data were the effects (relative risk) and global coverage of the individual interventions, obtained from prior literature and UNICEF statistics. The PAF of each intervention was ultimately used to enumerate the global morbidity episodes and mortalities that can be reduced by the interventions.

Population attributable fraction: WASH intervention impact assessment

To estimate the impact of WASH and other health interventions, Comparative Risk Assessment method was used (Ezzati et al. 2002). In essence, the method considers a risk factor and an health outcome, and determines the proportion of morbidity and mortality that would be reduced when the risk factor is diminished by an intervention; the proportional reduction in health burden is quantified as PAF (population attributable fraction) (Ezzati et al. 2002). Primarily used to assess the global health burden from risk factors, PAF has been widely used in the global burden of disease (GBD) studies (Ezzati et al. 2002, 2003; Black et al. 2013).

In this report, the PAF of the lack of WASH and other health interventions were determined for various health outcomes. The PAF for an intervention for a health outcome *x* was determined using the following equation, simplified from Ezzati et al. (2002):

$$PAF = \frac{(RR-1)P}{1+(RR-1)P}$$

where RR is relative risk of health outcome *x* without intervention, and P is the population proportion without intervention.

Joint population attributable fraction: WASH-integrated interventions impact assessment

Unfortunately, the joint effect of multiple interventions has not been extensively reported in the existing literature. Thus, for WASH-integrated interventions, the joint PAF was determined from the product of (1-PAF_i) term for each individual intervention (Ezzati et al. 2003). The joint PAF was determined using the following equation (Ezzati et al. 2003):

$$Joint\ PAF = 1 - \prod_{i=0}^{n}(1-PAF_i)$$

where n is the number of integrated interventions. By determining the product of multiple interventions rather than summation, the potential overlapping effect of the interventions are incorporated to a certain level.

Input data

Determining the PAF requires three sets of data: a) burden of morbidities and mortalities by the health outcome (except growth-related outcomes), b) global coverage of the intervention, and the c) relative risk of each health outcome with the lack of the intervention. The data were collected from WHO and Unicef statistics, and previous systematic reviews of health interventions. The collected data are presented in Table A 3 and Table A 4. The relative risk of health interventions are presented in Table 2 in Section 4.2.1.

Table A 3. Global disease burden for under-five children

	Morbidity (# million episodes)	Mortality (# deaths)	References
Diarrhea	9575	498889	(Troeger et al. 2017)
Pneumonia	1204	920136	(World Health Organization 2016; Walker et al. 2013)
Growth (stunting)	154.8	-	(UNICEF, WHO, and World Bank Group 2017)

Table A 4. Global coverage of interventions

Intervention	Without intervention	References
Water	29%	(UNICEF and World Health Organization 2017)
Sanitation	32%	(UNICEF and World Health Organization 2017)
Hygiene[a]	73%	(UNICEF and World Health Organization 2017)
Breastfeeding[b]	61%	(UNICEF 2013)
Nutrition (Zinc)	83%	(Wessells and Brown 2012)
Immunization (rotavirus)	75%	(UNICEF 2016)
Immunization (pneumococcal)	58%	(UNICEF 2016)
Immunization (*Hib*)	64%	(UNICEF 2016)
Complementary feeding[c]	78%	(UNICEF 2016)

a. For least developed countries; global average not available
b. Exclusive breastfeeding up to 6 months
c. Adequate diet, average of available country data; global average not available

Appendix 4. Comparison of findings to existing literature

It is noted that a similar study has been conducted by Pruss-Ustun et al. (2014), in which the fraction of global diarrhea burden attributable to water, sanitation, and hygiene were found. The difference between the Pruss-Ustun study (Prüss-Ustün et al. 2014) and the results of this report (Table 3) is from updated raw data, namely the change in the status of global WASH coverage (used to determine attributable diarrhea burden, see Appendix 3), and inclusion of the new evidence on the effect of WASH that were made available after the publication of the study (Table 2). The study Pruss-Ustun study reported 34%, 19% and 20% of diarrhea burden is attributable to poor water, sanitation, and hygiene, respectively (vs. 21%, 10%, 35% in Table 3, respectively).

Appendix 5. Effect of WASH-integrated interventions by disease outcomes

Table A 5. Under-five morbidities averted by WASH integrated interventions*

	Number of morbidities (% global <5 diarrhea and pneumonia morbidities) averted, Millions				
	Individual intervention	W-integrated	S-integrated	H-integrated	WASH-integrated
Breastfeeding (<2 years old)					
Diarrhea	1,355 (14%)	3,320 (35%)	2,265 (24%)	3,601 (38%)	5,533 (58%)
Pneumonia	198 (16%)	198 (16%)	198 (16%)	321 (27%)	321 (27%)
Sum	**1,552 (14%)**	**3,517 (33%)**	**2,462 (23%)**	**3,921 (36%)**	**4,606 (43%)**
Zinc supplementation					
Diarrhea	1,364 (14%)	3,327 (35%)	2,272 (24%)	3,608 (38%)	5,537 (58%)
Pneumonia	172 (14%)	172 (14%)	172 (14%)	298 (25%)	298 (25%)
Sum	**1,535 (14%)**	**3,498 (32%)**	**2,444 (23%)**	**3,905 (36%)**	**5,834 (54%)**
Diarrhea immunization (rotavirus)					
Diarrhea	2,363 (25%)	4,087 (43%)	3,161 (33%)	4,334 (45%)	6,028 (63%)
Pneumonia	-	-	-	147 (12%)	147 (12%)
Sum	**2,363 (22%)**	**4,087 (38%)**	**3,161 (29%)**	**4,481 (42%)**	**6,028 (56%)**
Pneumonia immunization (joint, pneumococcal and Hib)					
Diarrhea	-	2,289 (24%)	1,060 (11%)	2,617 (27%)	4,866 (51%)
Pneumonia	128 (11%)	128 (11%)	128 (11%)	406 (34%)	406 (34%)
Sum	**128 (1%)**	**2,417 (22%)**	**1,188 (11%)**	**3,023 (28%)**	**5,272 (49%)**

* W, S, H, WASH: Water, sanitation, hygiene, water sanitation & hygiene, respectively

Table A 6. Under-five deaths averted by WASH integrated interventions*,**

	Number of deaths (% global <5 diarrhea and pneumonia deaths) averted				
	Individual intervention	W-integrated	S-integrated	H-integrated	WASH-integrated
Breastfeeding (<2 years old)					
Diarrhea	179,470 (36%)	222,437 (45%)	199,361 (40%)	228,588 (46%)	341,804 (69%)
Pneumonia	265,155 (29%)	265,155 (29%)	265,155 (29%)	323,629 (35%)	344,921 (37%)
Sum	**444,625 (31%)**	**487,591 (34%)**	**464,516 (33%)**	**552,217 (39%)**	**686,725 (48%)**
Zinc supplementation					
Diarrhea	16,405 (3%)	131,748 (26%)	69,802 (14%)	148,262 (30%)	261,611 (52%)
Pneumonia	26,797 (3%)	26,797 (3%)	26,797 (3%)	135,597 (15%)	135,597 (15%)
Sum	**43,202 (3%)**	**158,545 (11%)**	**96,599 (7%)**	**283,858 (20%)**	**397,208 (28%)**
Diarrhea immunization (rotavirus)					
Diarrhea	59,191 (12%)	164,306 (33%)	107,853 (22%)	179,355 (36%)	282,653 (57%)
Pneumonia	-	-	-	112,064 (12%)	112,064 (12%)
Sum	**59,191 (4%)**	**164,306 (12%)**	**107,853 (8%)**	**291,419 (21%)**	**394,716 (28%)**
Pneumonia immunization (pneumococcal and Hib)					
Diarrhea	-	119,266 (24%)	55,213 (11%)	136,341 (27%)	253,544 (51%)
Pneumonia	101,934 (11%)	101,934 (11%)	101,934 (11%)	313,645 (34%)	313,645 (34%)
Sum	**101,934 (7%)**	**221,199 (16%)**	**157,147 (11%)**	**449,985 (32%)**	**567,189 (40%)**

* W, S, H, WASH: Water, sanitation, hygiene, water sanitation & hygiene, respectively
**Assumed relative risk of mortality= relative risk of morbidity, due to lack of rigorous evidence.