PATTERNS OF ENVIRONMENTAL FECAL EXPOSURE AND ASSOCIATIONS WITH CHILDHOOD ILLNESS IN RURAL BANGLADESH: A LATENT CLASS ANALYSIS

by

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Abstract

Inadequate sanitation, contaminated water and poor hygiene contribute to childhood disease morbidity and mortality through enteric and respiratory illness, trachoma, soil-transmitted helminths, parasitic diseases, environmental enteropathy and malnutrition. Multiple fecal exposures present different combinations of risk factors in low-income settings with limited infrastructure and poor hygiene behaviors. Large scale programs aimed to improve sanitation have an inconclusive health impact. Implementers still lean towards combining water, sanitation and hygiene interventions, despite limited evidence of additional health benefits from combined approaches.

The WASH Benefits Bangladesh study is a community-based cluster randomized trial in rural Bangladesh designed to assess the impact of single and combined water, sanitation, hygiene and nutrition interventions in single and combined interventions on child health. This dissertation aims to 1) assess the impact on respiratory illness on children under 3 years of age from single water, sanitation, hygiene and nutrition interventions when delivered alone or in combination; 2) identify sub groups of rural households that vary in risk for environmental fecal exposures using latent class analysis, 3) to examine whether the latent classes are associated with higher risks of childhood diarrheal and respiratory illness and 4) if water, sanitation, hygiene and nutrition interventions have differential impact in reducing disease prevalence across latent classes.

We found that water, sanitation and hygiene interventions reduce respiratory illness in young children. The same benefit was observed when water, sanitation and hygiene interventions were successfully integrated with nutrition interventions. Latent class analysis identified four subgroups (1-4) with increasing environmental risk profiles based on household characteristics in rural Bangladesh. Groups with unfavorable environmental conditions were associated with lower socioeconomic status, income and education. We found an increased risk of diarrheal disease in all latent subgroups compared to the '1-most favorable' class characterized by water sealed improved latrines, notably a 5-fold increase risk of diarrhea in the ‘4 most unfavorable’ group who did not have access to any latrines. For diarrheal diseases, we found reductions in reported diarrheal disease prevalence in index children following sanitation (S), handwashing (H), nutrition (N) and WSHN interventions compared to control households in the ‘3- unfavorable’ latent subgroup. This indicates that households with less sanitary conditions are more likely to benefit from interventions that reduce the transmission of pathogens.

Single WASH interventions may be effective in reducing respiratory illness and should be prioritized with limited resources. We highlighted the use of understanding the clusters of exposures to ensure interventions are adequately aligned to be effective. In low-income countries, where competing fecal pathways exist, improved health impact might be more practically achieved using approaches such as latent class analysis that incorporate interactions between environmental and socio-economic factors to inform holistic intervention strategies.

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Abbreviations

ANOVA	Analysis of variance
BLRT	Bootstrapped Likelihood Ratio Test
BIC	Bayesian Information Criterion
BRAC	Bangladesh Rural Advancement Committee
CI	Confidence Interval
CLTS	Community Led Total Sanitation
DALY	Disability Adjusted Life Years
DHS	Demographic Health Survey
EED	Environmental enteric dysfunction
icddr,b	International Center for Diarrheal Disease Research, Bangladesh
HAZ	Height for Age z-score
LAZ	Length for age z score
LCA	Latent class analysis
MST	Microbial source tracking
NGO	Non-Governmental Organization
ORS	Oral rehydration solution
PR	Prevalence ratio
RCT	Randomized controlled trial
RHF	Recommended home fluids
SES	Socioeconomic status
SD	Standard deviation
TLC	Total Sanitation Campaign
WASH	Water, Sanitation and Hygiene
WHO	The World Health Organization

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Chapter 1: Introduction

Diarrhea caused more than 1.3 million deaths worldwide and was the fourth leading cause death in children under 5 years of age in 2015[1]. Low income populations with poor water, sanitation and hygiene conditions, low access to healthcare bear the highest burden of diarrheal diseases[2]. In the first two years of life, a high proportion of death is attributed to due to diarrhea (72%) and pneumonia (81%)[3]. Severe diarrhea and pneumonia still rank among the most common reasons for hospital admission in children in low-income countries. The overlapping risk factors causing these two childhood illnesses contribute to morbidity, exacerbate growth and cognitive development of young children[3].

Approaches to reduce diarrhea include reducing fecal contamination in drinking water, improving sanitation and encouraging people to wash hands with soap[4]. Despite improvements in diarrheal diseases management, its morbidity has not reduced substantially in low-income countries[5]. Fecal pathogens can lead to a wide spectrum of serious illness including enteric disease, growth faltering, impaired cognitive development, enteric dysfunction, reduced response to vaccines and reduced immunity to fight infections increasing the risk of death [6,7]. Poor water and sanitation conditions exacerbate the cost of poverty through serious health consequences including enteric infections, malnutrition, and risk of non-communicable diseases[7]. The epidemiology of childhood diarrheal and respiratory diseases is discussed in the following sections, including the existing interventions available to prevent and treat these diseases. The evidence on the impact of water, sanitation and hygiene interventions is detailed and the case for analytical techniques to inform targeted interventions is also introduced.

1.1 Global epidemiology of diarrheal disease

Diarrhea is a leading infectious cause of morbidity and mortality among children under 5 years of age globally, causing an estimated 499,000 deaths in 2015[12]. The number of deaths fell by 34% between 2005 and 2015 after concerted efforts to improve water and sanitation worldwide. Low-income countries carry a high burden with up to 31% in South Asia[3]. Although the incidence of diarrhea fell from 3.4 to 2.9 episodes per child year from 1990-2010, it is still one of the leading causes of hospital admission in low-income countries[8]. Diarrhea related deaths are most common in children under 2 years of age (72%). Its incidence peaks between the age of 6-11 months with the most severe illness occurring between 0-11 months[9]. The heightened risk of morbidity and mortality during the first two years of life stresses the importance of intervening with preventive measures in this period. Most of the burden of childhood diarrhea lies in low income countries in South east Asia and Africa[10].

Diarrhea is defined as three or more loose stools, and diarrheal episode has at least 2 or 3 consecutive days free of diarrhea between them[11,12]. Diarrhea varies in its severity depending on the causative pathogens: loose stool with occasional vomiting; stool with blood and stomach cramps are known as dysentery; those with a large volume of watery stool with signs of severe dehydration; persistent diarrhea that continues for at least 2 weeks and those with acute vomiting. Moderate to severe diarrhea generally refers to the presence of dehydration signs (sunken eyes or skin turgor), dysentery, intravenous hydration recommendation or hospital admission[13].

Causes of childhood diarrhea range from metabolic problems and bowel irritation to exposure to pathogens and parasites. The Global Enteric Multicenter Study (GEMS) aims to describe the burden, etiology, and mortality of moderate to severe diarrhea in children 0-59 months through a prospective, age-stratified matched case-control study [14]. Four pathogens caused most of the moderate to severe diarrhea: rotavirus, Cryptosporidium, enterotoxigenic Escherichia coli producing a heat-stable toxin (ST-ETEC), and *Shigella. Aeromonas, V cholerae* O1 and *C jejuni* were important contributing pathogens in Asia[13]. Moderate to severe diarrhea was associated with 8.5 times higher odds [95% CI: 5.8-12.1] of death compared to controls and 88% of the deaths were in those <2 years old[13].

Transmission of diarrheal disease

Enteric pathogens are transmitted fecal-orally through complex pathways, often described using an F diagram depicting food, fields, fluids, fomites, fingers and flies (Fig 1.1). Human and animal feces contribute to the risk of diseases through interconnected transmission pathways. Theoretically, these pathways can be blocked through primary preventative interventions that restrict feces from the environment such as sanitation, or secondary interventions that target a transfer of pathogens such as water treatment, hand washing or other hygiene interventions such as fly control or food safety[15]. There is a wide range of interventions targeting water treatment, hand hygiene and containing and disposing of fecal matter that has been designed and tested. Many of these behaviors need to be repeated frequently and most interventions have a behavioral component targeting habit formation. Water, sanitation and hygiene interventions are often grouped together in strategic discussions and referred to as WASH[16]. Effectiveness and description of these interventions are covered in the following section, WASH interventions.

Repeated diarrheal episodes also have long term effects such as stunting, gut inflammation or environmental enteric dysfunction (EED), growth faltering and reduced cognitive capability, stunting and death[17–20]. Environmental risk factors are hard to change in low-income settings needing infrastructural or behavioral change to prevent further exposure.

Environmental enteric dysfunction

Tropical or environmental enteropathy also known as environmental enteric dysfunction (EED) has been described since the 1960s. It was first described as a reversible inflammatory disorder of the small intestine condition in adults and then in children and has since been documented in many countries[21–24]. EED, which may or may not be symptomatic, is characterized by changes in the outer layer of the small intestines which leads to reduced absorptive capacity, increased permeability and enables infiltration of inflammatory cells which would otherwise be prevented. There is ongoing effort to establish markers of intestinal inflammation and permeability, such as fecal biomarkers, sugar permeability tests through stool, urine collection, and blood tests[25–27].

The limited effectiveness of nutritional supplements in malnourished children under 2 years of age is explained using EED and consequent impaired nutrition absorption or appetite suppression[28]. EED has been used to explain up to 43% of growth faltering in infants and poor response to oral vaccines such as polio or rotavirus in children living in low-income settings[24]. Factors that could lead to EED include malnutrition, toxins, undernutrition or infections that lead to mucosal inflammation[29,30]. Contaminated environments are a common factor that enables EED in low-income settings[20,31]. A number of ongoing studies are looking at the effectiveness of WASH on EED in multisite low-income settings[32,33]. Improvements in sanitation, water quality, and hand hygiene could reduce the severity of intestinal malabsorption from EED either by preventing its acquisition or by reversing the pathology.

Interaction of undernutrition, infection, stunting and cognitive impairment

Undernutrition is estimated to cause 53% of all deaths in children globally[34]. The decline in nutritional status coincides with infections and is greatest in the first two years of life. A study in Bangladesh found that about half of the children between 5-12 months were stunted[35]. A vicious cycle between repeated diarrheal episodes has been proposed, where infections cause malnutrition which in turn causes increased susceptibility to diarrhea frequency by 37% and duration by 73%[36]. The potential of increased vulnerability to infections can lead to smaller intervals between infectious episodes[37]. Nutrient losses due to mal-absorption of nutrients can lead to worsening nutritional status over time especially when faced with repeated assaults[38,39]. Children who are stunted, underweight and/or wasted are at greater risk of death from diarrhea, pneumonia, measles, and other infectious diseases[38–40] (Figure 1.2).

Catch-up growth after diarrheal episodes in children might compensate for the weight loss during the illness but this phenomenon has been debated[6]. Stunting is a common manifestation of undernutrition in developing countries and is associated with increased morbidity, cognitive delays, and mortality[41]. A study in rural Bangladesh found an association between geophagia with EED and stunting[42,43]. Targeted interventions that reduce exposure to fecal pathogens and prevent diarrheal episodes in the first two years of life are critical. Interventions that reduce risk of diarrhea can have multiplicative effects on a child's health in both the short and the long term.

Children in low-income countries suffer from growth faltering in the first 2 years of life due to preventable causes such as malnutrition and infection[44]. Interventions that have targeted breastfeeding, complementary feeding and nutritional supplements led to small gains in length for age[25,28]. This emphasizes the importance of interventions that reduce the risk of infections that lead to undernutrition and gut inflammation. Mechanisms from diarrheal illness to stunting include reduced nutrient absorption capability, reduced appetite and acute micronutrient loss such as zinc. EED has also been suggested to be a pathway linking enteric diseases to stunting[6,23].

1.2 Overlapping risk factors with respiratory illness

Acute respiratory infections and diarrheal diseases are the most frequent cause of childhood morbidity, mortality and hospital attendance in low- to middle-income countries. Both these diseases are preventable but still account for about 25% of all child deaths[2]. The risk factors for pneumonia and diarrhea overlap, especially those associated with poverty, poor living conditions, sub optimal breastfeeding, zinc deficiency and malnutrition[3,45,46] (Figure 1.2). It also includes crowding and poor air quality, characteristics that are common in poor households [47,48]. Poor environmental conditions enable transmission of pathogens and exacerbate infectious diseases contributing to poor nutrition, cognitive deficits and weak immunity in young children [6,49]. Zinc supplementation in children is associated with an 18% reduction in diarrhea mortality and 15% pneumonia mortality[50]. Community case management by health workers in resource poor settings were associated with a 32% reduction in pneumonia mortality and 160% increase in ORS and 80% increase in zinc use for diarrhea management but little impact on diarrheal mortality[51]. Interventions leading to reduction in diarrheal disease morbidity could improve child health through subsequent reduction in pneumonia. Episodes of diarrhea may increase the risk of pneumonia in malnourished children. Both diseases can be reduced through improved hygiene practices such as hand washing with soap which is often poorly practiced in low resource settings[52]. Improvements in environmental infrastructure, better living conditions may alter respiratory pathogen transmission rates through increased separation between household members[53]. Simple interventions such as handwashing with soap have been shown to reduce acute respiratory infection by blocking transmission of respiratory pathogens [54,55]. Studies have shown that improvements in water quality and sanitation may reduce the risk of respiratory illnesses depending on their effectiveness and scale[56,57]. Overlapping risk factors for respiratory illnesses suggest that combining nutrition and interventions improving water, sanitation and hygiene conditions in resource-poor settings, could lead to larger reductions in childhood illness compared to each component alone[58–60]. Hence, WASH interventions that improve environmental sanitation are also pertinent for respiratory illness burden.

1.3 Interventions targeting childhood diseases

Effective interventions that can prevent or manage diarrheal and respiratory illness episodes in children exist. These include water, sanitation and hygiene interventions, vaccines, oral rehydration therapy and zinc, breastfeeding and complementary feeding. If these were effectively scaled up more than two thirds of child deaths globally could be prevented [61,62]. Effective integration of interventions would help guide allocation of public and donor funds to achieve the maximum health impact given limited resources in low-income countries[45,63,64].

Vaccines

Vaccine preventable pneumonias, particularly those caused by *Streptococcus pneumoniae*, *Haemophilus influenzae* type b, and the influenza virus account for at least a third of severe episodes and two-thirds of deaths[3]. Nearly a third of episodes of severe diarrhoea are preventable by vaccination. Rotavirus is the leading cause of vaccine-preventable diarrhea among children under-five and is associated with approximately 28% of diarrheal deaths[4]. There are two licensed vaccines for rotavirus, RotaTeq and Rotarix (GlaxoSmithKline, Rixensart, Belgium). WHO recommends the inclusion of rotavirus vaccination in all national immunization programs and many countries have implemented it. Reviews show that rotavirus vaccines are effective but the effect varies, preventing fewer severe diarrhea in Asia (42.7%) and sub-Saharan Africa (50%) than in developed countries (91%)[65]. The difference in effectiveness may be due to the varying circulating strains, levels of diarrheal disease, gut inflammation, co infection with other pathogens and malnutrition[65,66]. There are two WHO licensed vaccines for cholera, a killed oral vaccine Dukoral and a killed whole cell vaccine called Sanchol in South Asia, with a reported 67% 3 year post vaccination protection[67]. A review showed that cholera vaccines led to 52% reduction in cholera incidence[68]. There is currently no effective licensed vaccine against ETEC or shigella but candidates are being tested in Phase 3 trials[68].

Breastfeeding

Suboptimal breastfeeding (a term used to denote deviation from WHO recommendations for ideal breastfeeding practices) increase the risk of both morbidity and mortality from diarrhea in children less than 2 years of age. Not breastfeeding increases diarrhea incidence by 165% (RR 2.65, 95% CI: 1.72-4.07) in children under 6 months, 32% (1·32, 1·06–1·63) in children aged 6–11 months, and a 32% (1·32, 1·06-1·63) in those aged 12–23 months. It also increased diarrhea mortality by 47% (1·47, 0·67–3·25) in those aged 6–11 months, and a 157% (2·57, 1·10–6·01) increase in those aged 12–23 months[69]. Breastfeeding provides adequate nutrition in the early months of life including essential vitamins and micronutrients. It also increases resistance to infections through transferring maternal antibodies and minimizes fecal-oral transmission through contaminated fluids and food which may have been used otherwise[69,70].

Oral rehydration solution and zinc: Oral rehydration therapy contains glucose and electrolytes treat dehydration from diarrhea from any cause in all ages[71]. Following WHO recommendations, ORS including recommended home fluids (RHFs) such as rice water and sugar salt solution, is used as a diarrhea control intervention to use early in the diarrhea episode to prevent dehydration and subsequent consequences. ORS is estimated to prevent 93% of diarrhea deaths in children under 5 years[103]. In addition to ORS and continued feeding, zinc is recommended for diarrhea treatment. Zinc supplementation had a significant and beneficial impact on the clinical course of acute diarrhea, reducing both its duration and severity as well as reducing subsequent episodes. It is also associated with a 13% - 23% reduction in diarrhea mortality in children under 5 in low-income countries [50,72].

Nutritional supplements

The two years of life is a critical window for intervention in growth and development: infection and poor nutrition during this window can negatively impact an individual's long-term cognitive development and lifetime physiologic trajectory [18,64]. Nutritional interventions during the first few years of life have long term impact improving schooling and income in adolescents and adults [73,74] . A systematic review of the impacts of complementary feeding and supplementation interventions reports that even the most successful of these interventions correct approximately a third of the mean growth deficit for African and Southeast Asian children[28].Nutritional supplementation may be necessary but not sufficient to eliminate growth shortfalls due to chronic infection and EED[75]. Nutritionists have hypothesized that reducing a child's fecal bacteria exposure during the first years of life through improved sanitation, handwashing or water treatment may improve gut function and subsequent growth [20]. In settings with high food insecurity, lipid based nutritional supplementation (LNS) addresses gross energy shortfalls and provides essential micronutrients[76]. Combining nutrient supplementation with improved environmental sanitation might be more effective in reducing risk of infection and addressing stunting deficits in low-income counties[20].

1.4 Water, sanitation and hygiene interventions (WASH)

Poor WASH conditions are associated with 2.4 million deaths due to malnutrition from diarrhea and 6.6% of the global burden of disease and disability[77]. Globally 2.5 billion people lack s to improved sanitation and 1.1 billion still defecate in the open[16]. An estimated 783 million people live without improved water sources. Diarrhoeal DALYs have reduced by 13·4% due to improvements in safe water and sanitation between 2005-2015 [1]. Despite large scale campaigns to promote hand washing with soap, actual practice among low-income communities is low especially after fecal contact (14%) and before handling food (<1%)[78]. The health consequences of lack of access to improved water, sanitation and hygiene (WASH) has been estimated to cause 1.5% of total disease burden and 58% of diarrheal diseases in low to middle income countries[79]. Improved WASH conditions are effective in reducing morbidity from various diseases including diarrhea, respiratory illness, malaria, trachoma, helminthes and malnutrition[80–82].

Unsafe water and sanitation impact more than health including education, development, mental health around violence and sexual harassment especially for rural women[82–84].

The Declaration of Alma Ata in 1978 highlighted the importance of primary health care included “an adequate supply of safe water and basic sanitation” as one of its eight key elements[85]. The Millennium Development Goals (MDG) included reducing half the proportion of population without access to basic sanitation by 2015[86]. MDGs has been critical in setting goals to achieve in crucial aspects of health and Bangladesh has been one of those who have achieved their aims in reducing childhood mortality. In the WASH sector, there has been large scale initiatives and push from the policy level to increase sanitation coverage. Examples include Total Sanitation Campaign (TLC) in India, Uganda Village Project (UVP) in Uganda, and BRAC WASH program in Bangladesh. However, within the existing literature generating causal inference of health impact from sanitation is both expensive and difficult given multi faceted sources of pathogen transmission[87]. There are numerous water, sanitation and hygiene interventions that have been tested to reduce fecal oral transmission of enteric pathogens[77]. WASH interventions are categorized in the broad groups that have focused on the following:

Hygiene: Promotion of hygiene and health education, hand washing with soap, soapy water, hand sanitizers at specific occasions where transmission of pathogens is likely.

Sanitation: Provision on improved latrines; excreta disposal tools including potties, scoops, diapers; sewer connections; animal feces management near or around the household.

Water quality: Treatment of drinking water to remove microbial contaminants; proper storage and handling; improving water supply such as installation of hand pumps, piped water etc.

Multiple WASH: Any combinations of water, sanitation and hygiene; many WASH interventions are also being tested in combination with nutrition supplements and deworming programs.

These interventions span from targeting individual behavior change, to the household, school community and city level. Several reviews have been conducted to determine the impact of WASH interventions on diarrheal disease[88]. Demonstrated effectiveness of each component in WASH is discussed next.

Hygiene interventions

Washing hands with soap can reduce the risk of diarrheal diseases by an estimated 30-40%[54]. Despite knowledge of the benefits of hand washing, only an estimated 19% of people worldwide wash their hands with soap following fecal contact, with a range between 13-17% in low to middle income countries and 42-49% in high income countries[54]. Hand washing has been shown to have a large protective impact on both diarrheal and respiratory illness, child motor and cognitive development with no impact on stunting[52]. There are context specific barriers to hand washing including long standing habits, threat perception and use of different hand washing agents[89,90]. A review from studies in Asia, Africa and Latin America which found only 17% of caretakers washed hands with soap after toilet use, identified three kinds of hygiene behaviors: motivated, habitual and planned[91]. Emotional motivators to wash hands were more effective than rational knowledge of disease prevention, particularly nurturing, status and disgust [91,92]. To target effective interruption of pathogens, critical time points have been strategically promoted with suggested behavior change in many studies particularly following fecal contact or food handling[93]. Efforts to change handwashing behavior on a large scale is difficult and ways to effectively promote and sustain hand washing is an area of active research[78]. Studies have shown health and awareness based motivation is insufficient alone in changing behavior[94]. For example, in India an extensive educational program with Glow-germ demonstrations found no increase in hand washing rates[95]. Scott et al. noted that the strongest motivations to hand wash centered around social acceptance, nurturance, disgust and smell of feces[96].

Hygiene also broadly captures general cleanliness near or within the household although epidemiological evidence linking this to health outcome is scarce. Food hygiene is also an area of active research to limit contamination of food from flies, hands, utensils or duration of storage[97]. Observational studies show that maternal knowledge of hygienic practices around food handling is associated with childhood diarrhea[98]. Targeted behavior change around food handling including regular hand washing and reheating can reduce the bacterial contamination of food prepared in low-income potentially unhygienic conditions[99].

Application of this in improving the quality of weaning food has potential in impacting risk of childhood diarrhea. Impact of hand washing on diarrhea related or all cause mortality is not known.

Sanitation interventions

Sanitation broadly refers to adequate sewage disposal in public health, for the sake of cleanliness and hygiene to protect health in households and communities (WHO 2014). In WASH, however it refers to access to improved toilets or behaviors which adequately separate feces from the environment. Evidence that improving sanitation coverage leads to reduction of risk from diarrhea is limited. While infrastructure based sewerage coverage in urban settings have proved effective, up to 60% when baseline sanitation conditions were poor, they are expensive to implement and maintain[100]. A large study to evaluate the impact of shared, onsite urban sanitation intervention program on enteric infections in children is underway[101].

Latrine installations that are typically used in rural sanitation interventions are not connected to a networked sewerage system. Studies have reported that inadequate sanitation contributes to the morbidity from diarrhea in addition to soil transmitted helminthes, trachoma and malnutrition [81,88,102]. A recent review studying the impact of sanitation interventions showed only modest impact on latrine coverage and use[103]. Meta analyses from 14 countries showed overall relative risk for improved over unimproved sanitation on diarrhea, was 0.72 (0.59, 0.88)[104]. These systematic reviews emphasized the use of different latrine models, poor study designs, measurement indicators and those that measured the combined effect of sanitation when delivered with water and hygiene interventions that limited inferences of specific sanitation on health [80,105].

Recent cluster randomized trials that have carefully evaluated latrine installations in rural India, Odisha[106] and Madhya Pradesh[107] found no health impact on health, including diarrheal, helminthes, anemia or malnutrition. Insufficient coverage and use of latrines may be the most likely causes for the absence of conclusive health impact because there was no microbial evidence of reduced fecal pathogen exposure despite increased latrine coverage of >50%. Indeed, microbial assessments of fecal indicator bacteria might be highly variable temporally due to multiple sources of contamination to reflect changes in latrine types[108] [46, 135]. An RCT in Mali intervening with CLTS found reduced open defecation practices led to improvements in child growth in children less than 2 years of age but not diarrhea[109]. Similarly, a randomized study in Maharashtra, India found a change in height following latrine installation[110]. Challenges in reducing enteric disease prevalence include widespread continued open defecation, unhygienic child feces disposal and persistent animal feces at the village level[106,111]. Interventions targeting sanitation have focused on individual technologies such as improved latrines, child potties or diapers. In low-income settings where solid waste disposal is linked to diarrhea may highlight the disposal of excreta at that site attracting flies[112]. Fly control have been associated with a reduction in risk for diarrhea (22-26%) and trachoma[113]. Provision of latrines is an effective fly control intervention that reduced the number of flies in intervention villages and reduced trachoma prevalence by 30% in the Gambia[114].

Access to improved WASH is inequitably distributed which has social and economic implications, especially since it is often scarce in low-income rural settings[115]. Majority of those who lack sanitation access live in rural settings. Lack of access to improved sanitation is particularly difficult for women and can impact school attendance in girls and mental health[116,117118]. There are complex barriers to sanitation adoption that are difficult to target through programmatic efforts. In rural India, open defecation was reportedly preferred despite access to a latrine, citing perceived convenience, comfort and low benefits of latrine use[119]. Changing social norms through collective awareness has been used in community led total sanitation (CLTS) activities which has been implemented with mixed impact in many countries[120]. Triggering disgust and shame of practices in a community encourage them to achieve total sanitation but effectiveness of this intervention depends on multiple factors such as homogeneity of the community, availability of resources and post triggering activities [120]. Cost and ability to afford hardware is a barrier to improving sanitation conditions and research is being done to target community financing options to provide economic incentives to achieve goals[121]. There are many challenges in addressing the intermingled routes of fecal contamination in low resource settings. Effective interventions require understanding of the context and driving factors contributing to environmental complexities to ensure desired improvements and health impact[122].

Bangladesh and WASH interventions

Bangladesh is a low lying, riverine delta in Southern Asia, bordering the Bay of Bengal between India and Burma. It is one of the most densely populated countries in the world with 66% still living in rural areas[127]. Under 5 mortality in Bangladesh has reduced but is still high at 46 per 1000 live births (2010-14). Stunting in children under 5 years have decreased from 51% (2004) to 36% (2014)[128]. Fifty five percent of infants are exclusively breastfed for the first 6 months although complementary foods are common before they reach one year (DHS 2014).

Bangladesh is prone to flooding from seasonal monsoons and cyclones which contaminates water sources and destroys sanitation facilities. Poverty and poor living conditions combine to propagate transmission of pathogens in both the household and the compound setting in rural and urban settings. The underprivileged who live in resource limited conditions are not homogenous and face various risks from conditions that contribute to their poverty [129]. BRAC and other NGOs operating nationwide target many of their interventions and programs to the hardcore poor or ultra-poor to maximize their impact [130,131]. Indeed, burden from infectious disease remains high, with an estimated 20,000 children die annually due to diarrheal disease and 26,000 from pneumonia[4]. Open defecation among young children remains a persistent problem despite increases in latrine coverage. Bangladesh has the second highest level of unhygienic disposal of child feces in the Southern Asia region, despite 96% having access to a latrine[111]. Reported unsafe disposal of child feces associated with greater diarrhea risk and impaired growth in children[132]. Sanitation and hygiene interventions have major potential for enhancing human wellbeing in rural areas. A network of NGOs has stepped up across all districts to address WASH needs. The objective includes working with the community to develop their own action plans, improve latrine coverage and usage, usage of safe drinking water and improved hygiene practices especially hand washing with soap at critical times. Community Led Total Sanitation (CLTS), described earlier was developed in the villages of Bangladesh and has since been adapted and implemented in several countries with mixed results[120]. The effectiveness of this intervention depends of several characteristics of the community it is implemented in, especially with regards to their cohesion, homogeneity and ability to source quality latrine to build hygienic latrines[120].

Many of the interventions that reduced child mortality in Bangladesh include those targeting maternal and child health together, such as increasing antenatal care, improving maternal nutrition during pregnancies and vaccination[10]. Affordable and effective interventions that require habitual behaviors linked to improved child health fail to achieve similar impact when scaled up. Difficulties in integrating, implementing and sustaining interventions in addition to weakness in delivery systems, targeting strategies and resource management contribute to inefficiencies when scaled up[133]. An evaluation of a large scale program to improve hygiene, sanitation and water supply for 20 million people in Bangladesh found no impact on acute respiratory illness or diarrheal disease in young children[78].

Given that recent scaled up sanitation programs have failed to demonstrate significant child health improvements, it is important to assess whether effective WASH interventions delivered to achieve high uptake lead to any improvements in child health [134]. Evidence comparing the health benefits of improvements in sanitation, water quality, and hygiene interventions to each other and when delivered together is critical for guiding the allocation of public and donor funds to achieve the maximum health impact given limited resources. It is also important to know when uniform interventions are delivered to a heterogeneous population with varying baseline risk factors, whether certain subgroups within the population benefit more from the interventions compared to others. First, such evidence could help to maximize the value of existing resources by shifting expenditures to the most cost-effective interventions. In addition, such evidence could help generate more resources for these sectors by resolving uncertainty regarding the efficacy of water, sanitation, and hygiene interventions and identifying simple technologies and approaches to behavior change that cost-effectively improve health and could be replicated at scale. One approach, a latent class analysis is explored in this dissertation to enable better targeting of the population when scaling up cost effective interventions.

1.5 Latent class analysis

Latent class analysis (LCA) is a data reduction tool used to discover subtypes of cases based on their shared features measured through their responses to categorical variables[135]. It is commonly used in diagnostics to identify disease subtypes, in psychology, marketing, sociology and education to identify and study naturally occurring distinct subgroups. Investigating how to group people with common characteristics is of interest for several reasons: 1) It allows description of groups that exist within a larger population; 2) allows analysis of associated features such as demographic characteristics; risks or behaviors; and 3) enables effective targeting of interventions to maximize impact. There are published discussions of its utility in behavior analysis that categorize shoppers or consumers in business and advertising sectors to inform strategic focus for the marketing of products[136,137]. In sociology, demography and psychology, methods such as latent class analysis are used to surpass standard categorizations such as race, ethnicity or socio economic position that are limited in capturing features of specific sub populations important for research objectives[138,139]. Household access to safe drinking water, sanitation, hygienic behavior and building materials can be a function of income, education, socio economic status. We investigated the use latent class analysis to describe households using one multidimensional indicator, which can then be integrated in epidemiological analyses. Given the overall minimal impact of sanitation interventions in large well studied populations[107,140], it is important to capture whether the interventions are effective in sub populations.

LCA is particularly appropriate for data on the presence or absence of symptoms such indicators typically captured through surveys characterizing household water, sanitation and hygiene conditions. This analysis contrasts with methods such as factor analysis, which is also used to study underlying latent structures. However, it uses continuous indicators to produce continuous and usually normally distributed latent variables. Factor analysis is commonly used in construction of indices or scales.

1.6 Objectives

This dissertation research has three main objectives:

1) **Effect of water, sanitation, hygiene and nutrition interventions on respiratory illness in children in rural Bangladesh: A randomized controlled trial**
    a. To determine if water, sanitation, hygiene and nutrition interventions when delivered individually or in combination has any impact on care giver reported respiratory illness in children under 3 years of age in rural Bangladesh
2) **Define using latent class analysis, environmental risk factors for fecal contamination that coexist at the household level in rural Bangladesh**
    a. To identify subgroups to categorize risk factors by examining patterns in water, sanitation and hygiene related characteristics in rural households in Bangladesh
3) **Effect of water, sanitation, hygiene and nutrition interventions on childhood illness across latent subgroups of environmental risk factors in rural Bangladesh**

    a. To determine whether the single water (W), sanitation (S), hygiene (H), nutrition (N) and combined WSH and WSHN interventions had differential impact across latent classes. We hypothesized that children from households in classes with characteristics indicative of higher fecal contamination would have relatively higher reduction of childhood illness from the interventions compared to those households with lower contamination levels.

    b. To determine if latent classes were associated with childhood diarrheal and respiratory illness in young children. We hypothesized that children from households in classes indicative of higher contamination would have relatively higher prevalence of childhood illness compared to those households with lower contamination levels.

Figure 1.1: Transmission pathways of fecal-oral diseases (Source: Pruss et al. [38])

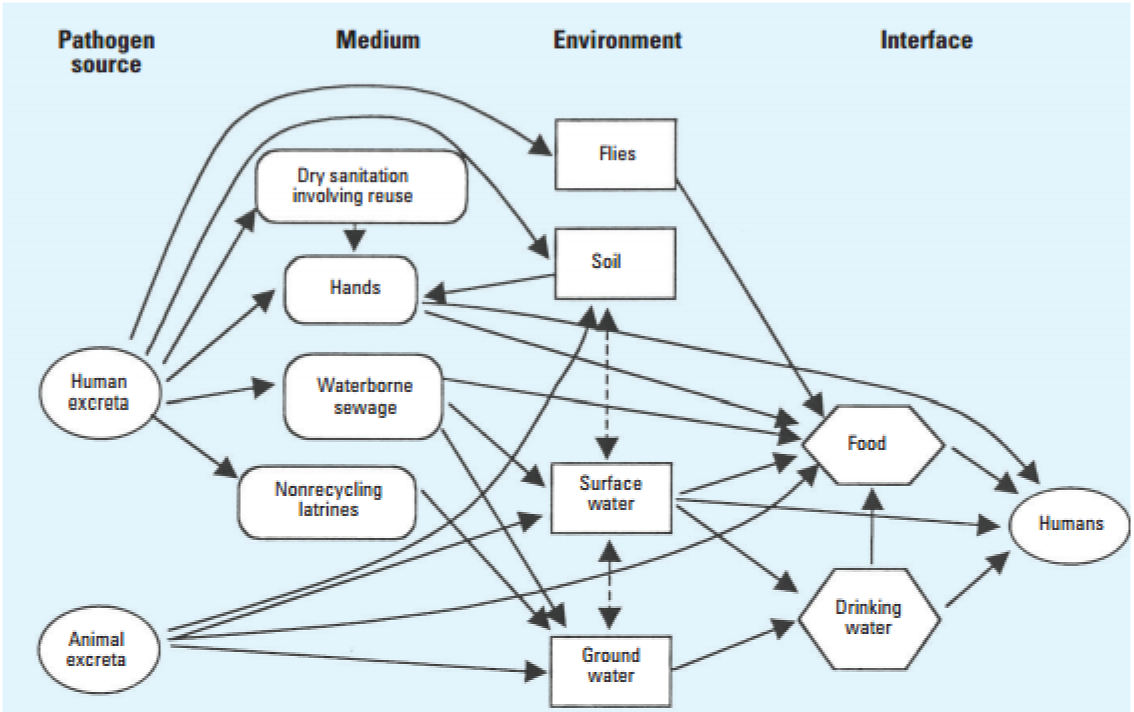
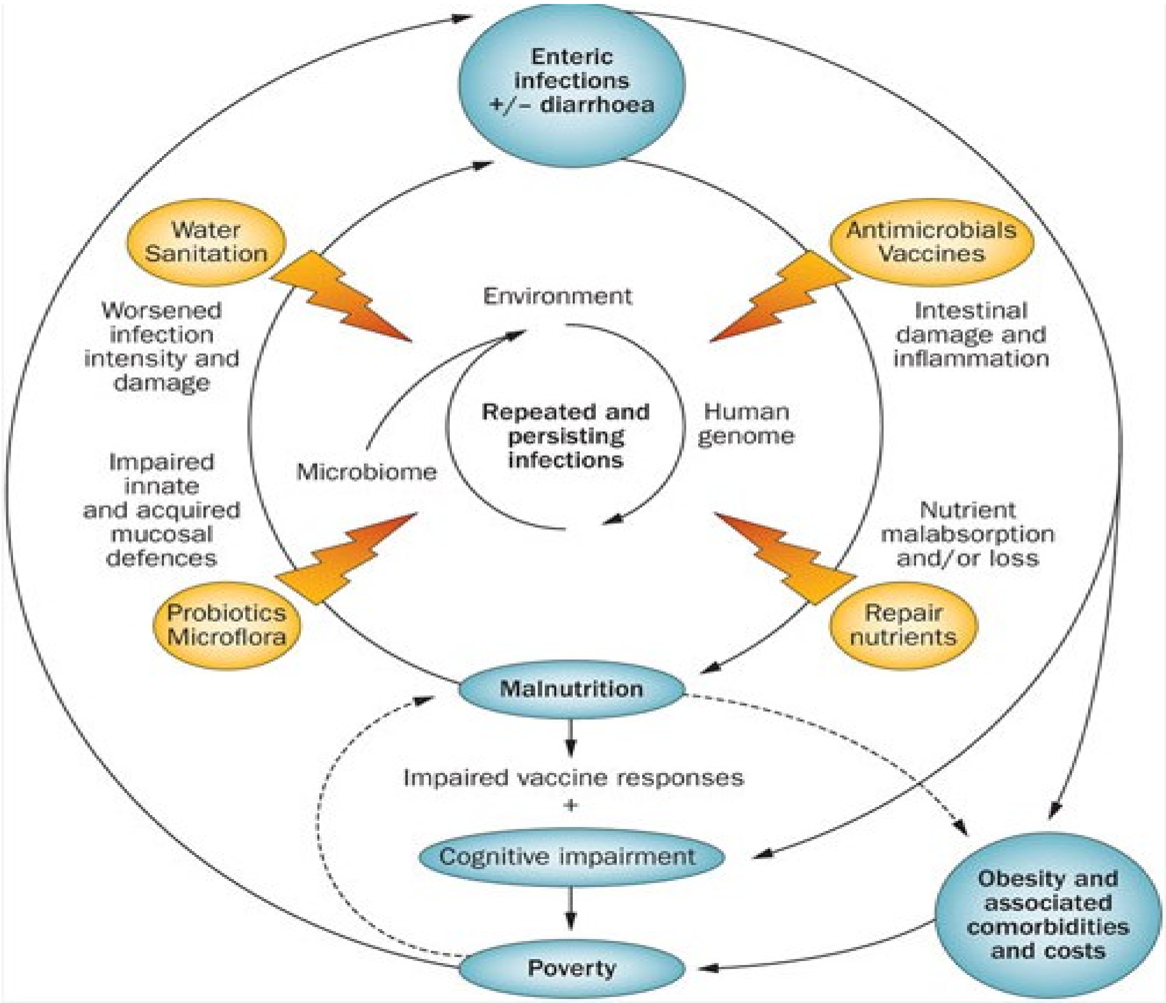


Figure 1.2: The vicious cycles of diseases of poverty including childhood enteric diseases, malnutrition and chronic illness [Source: Guerrant et. al. 2013] [7]



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Chapter 2: Parent study- WASH Benefits Bangladesh

Details related to the statistical methods and analyses for each specific aim are included in the aim-specific chapters (Chapters 3. 4. 5). These studies were nested within a community based cluster randomized trial called WASH Benefits in rural Bangladesh. This chapter outlines details about the design and rationale for the parent study to provide context for the results to follow.

2.1 Parent trial

WASH Benefits includes two cluster-randomized trials designed to assess the effect of improvements in water quality, sanitation, hand washing and child nutrition, alone and in combination, to rural households with pregnant women in Kenya and Bangladesh. The study aims to measure child growth and health outcomes arising from low cost WASH interventions and nutrition supplements and evaluate the degree to which in resource poor settings, there is added health benefits delivering concurrent interventions versus individual ones. They will also measure the impact of WASH and nutrition interventions on intestinal parasitic infection prevalence and intensity. In addition, they will measure the impact of interactions between the water, sanitation, hygiene and nutritional interventions and the mother and child's intestinal microbiome, immune function, internal biochemical environment and genetic disposition.

The study's design and rationale have been reported in detail elsewhere[1]. The study protocol was approved by human subjects committees at icddr,b (PR-11063), the University of California, Berkeley (2011-09-3652) and Stanford University (25863). The trials were also registered on (http://www.clinicaltrials.gov): NCT01590095 (Bangladesh). For the nested studies, we focused on the rural Bangladesh trial. The study began enrollment in May 2012 and ended in December 2015. WASH Benefits Bangladesh was led and implemented by the International Center for Diarrheal Disease Research, Bangladesh (icddr,b).

Study setting

Bangladesh is a low lying, flood prone delta in Southern Asia, bordering the Bay of Bengal between India and Burma. The study population in Bangladesh was located in rural villages from four central and north-east districts: Gazipur, Kishorgonj, Mymensingh and Tangail (Figure 1). These rural communities generally have poor sanitation conditions and use shallow tube wells as their main source of drinking water, which are frequently contaminated with fecal bacteria[2].

Participants

Rural households in Bangladesh are usually arranged around a common courtyard, where patrilineally linked families live close together. Research assistants approached compounds from villages and identified households with an eligible pregnant mother. If the household did not report high iron in their drinking water, their GPS coordinates were taken. Clusters of households with pregnant women were constructed for research assistants to approach and enroll for the trial, given that they were not participating in any major on-going water, sanitation or nutrition programs at the time of enrollment and planned in the area in the next 2 years. They were also not located in coastal regions or flood prone areas at risk of being completely submerged during the monsoon season.

Each cluster consisted of 8 households with a pregnant woman and could be visited by a single promoter by walking. The clusters were also separated by a ~15 minute walking distance from each other to avoid contamination of interventions. Children under 3 years in the compounds with the eligible pregnant woman could participate for disease morbidity measurements.

Randomization and masking

Baseline data on household characteristics and water, sanitation and hygiene habits were collected from participants prior to randomization. Blocks of 8 clusters were then randomized into 1) drinking water treatment and safe storage, 2) sanitation, 3) handwashing, 4) combined water + sanitation + handwashing (WSH) 5) nutrition, 6) combined nutrition + WSH and 7) non-intervention control group. The control arm was double sized to improve precision of estimates when compared to multiple arms. The design and size of each arm is shown in Figure 2. Each cluster received one of these interventions, and disease prevalence of children (n=8) from these clusters were compared to that of children from a double sized (i.e. two control clusters, n=16) within the same block. Further details regarding randomization and design has also been published[1]. Since the interventions were distributed for free with supplementary promotion by a promoter, masking of the subjects or the data collectors to arm assignment was not possible. The research team who implemented the intervention was separate from the data collection team. The analysis for Chapter 3 on respiratory outcomes was done using re-randomized uninformative assignments to enable masked statistical analyses from raw datasets. Results were unmasked once statistical analysis was completed.

Interventions

The interventions implemented in this trial were developed following two years of iterative piloting and testing. All interventions were promoted by a locally hired and trained female promoter. The sanitation intervention hardware included dual pit latrines, a potty for young children and a sani-scoop for removal of child or animal feces from the environment and their safe disposal in the latrine[3]. This sanitation intervention targeted all households in a compound. The water treatment intervention comprised encouraging households with the index child, to treat their drinking water with sodium dichloroisocyanurate (NaDCC) tablets (Medentech, Wexford, Ireland) and store it in the distributed safe storage containers4. The hygiene intervention included the provision of a handwashing station and soapy water[56]. The nutrition intervention was index child specific, and included lipid based nutrient supplement (Nutriset, Malaunay, France) for children 6-24 months. The promoters instructed the 10g sachet to be fed to the child twice daily in addition to diverse nutrient rich diets.

The promoters who promoted these interventions had over 8 years of formal education and attended multiple training sessions to address technical skills; active listening and troubleshooting while working in the community. They conducted weekly household visits and bi weekly courtyard sessions promoting the use of interventions. The frequency of these activities was reduced following the first 6 months according to the project needs. They were paid an equivalent of 20 USD monthly for their work. These are accompanied with a behavior change program that encourages regular use of these hardware components through periodic household visits. We used the Integrated Behavioural Model for Water Sanitation and Hygiene to develop the interventions and guide the behavior change strategy[7]. Further details on the interventions have been published [1].

Data collection

The interventions took approximately 3 months to deliver from the baseline survey. The follow-up rounds are planned for 12 and 24 months after intervention delivery. Trained field workers conducted interviews in the enrolled households with the primary female care giver of the youngest child in the household. They collected information on hand washing, sanitation facilities and behavior through participant self report as well as direct observations. The cross sectional survey included demographic information, data on households' hygiene, sanitation, water source and treatment status, as well as household construction and possessions. Child's nutritional intake was recorded using a 24 hour food recall and direct observation of LNS packets in the households. All data used in this thesis was collected through the surveys. Details on specific aim related outcomes are included in the respective chapters.

2.2 Tables and figures

Figure 2.1: Map of districts and sub districts enrolled in the WASH Benefits, Bangladesh site

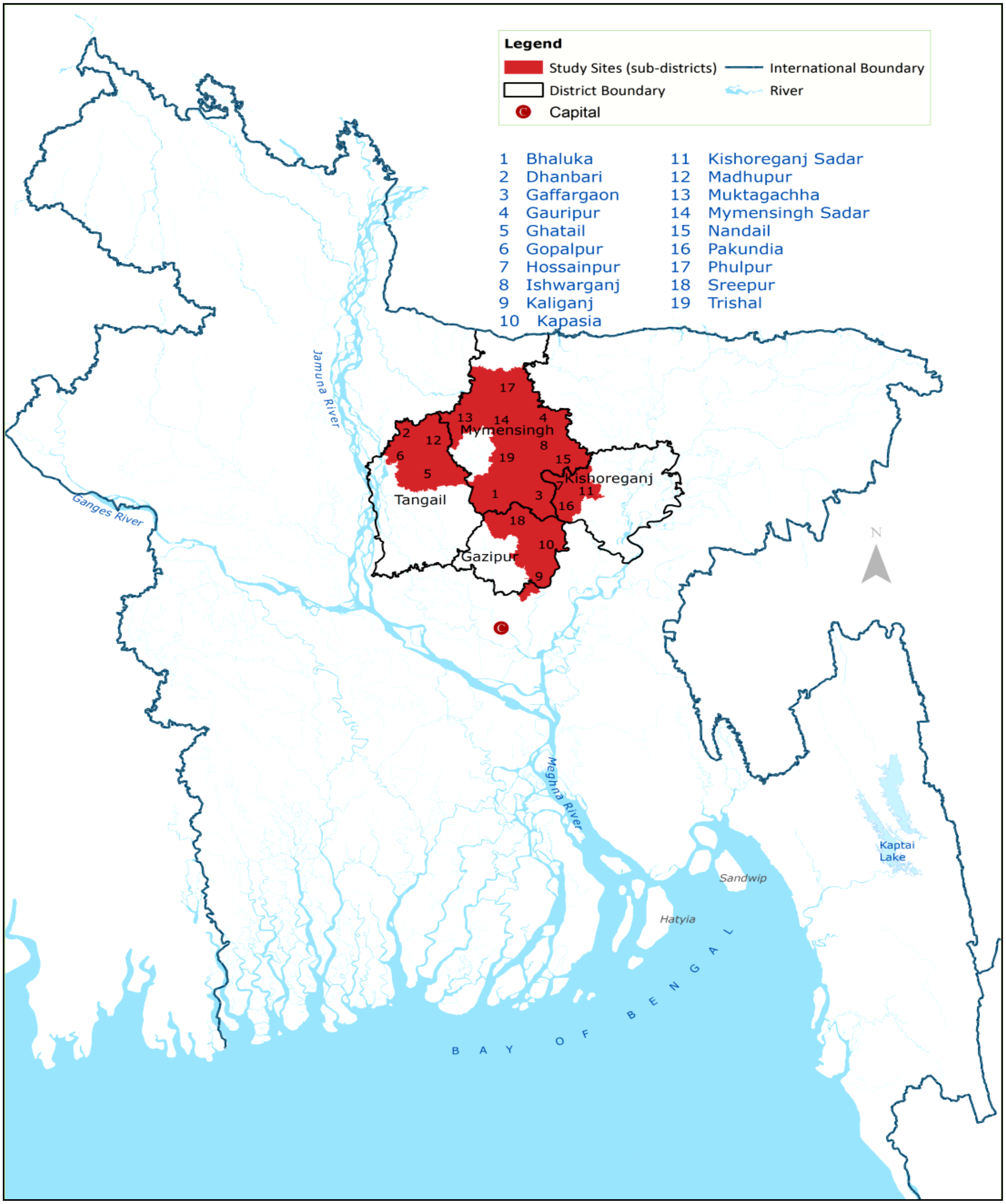


Figure 2.2: WASH Benefits randomized controlled study design overview

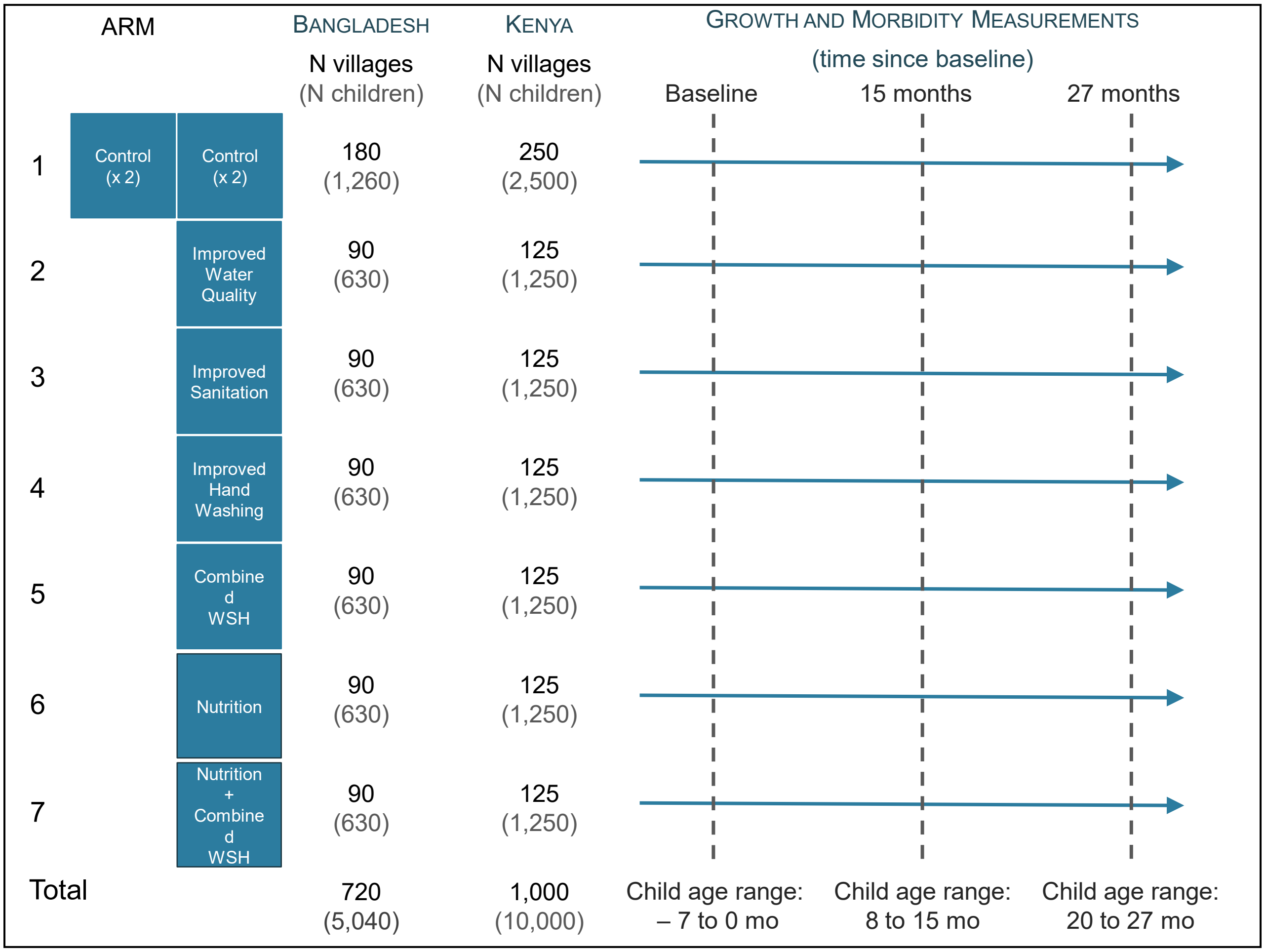
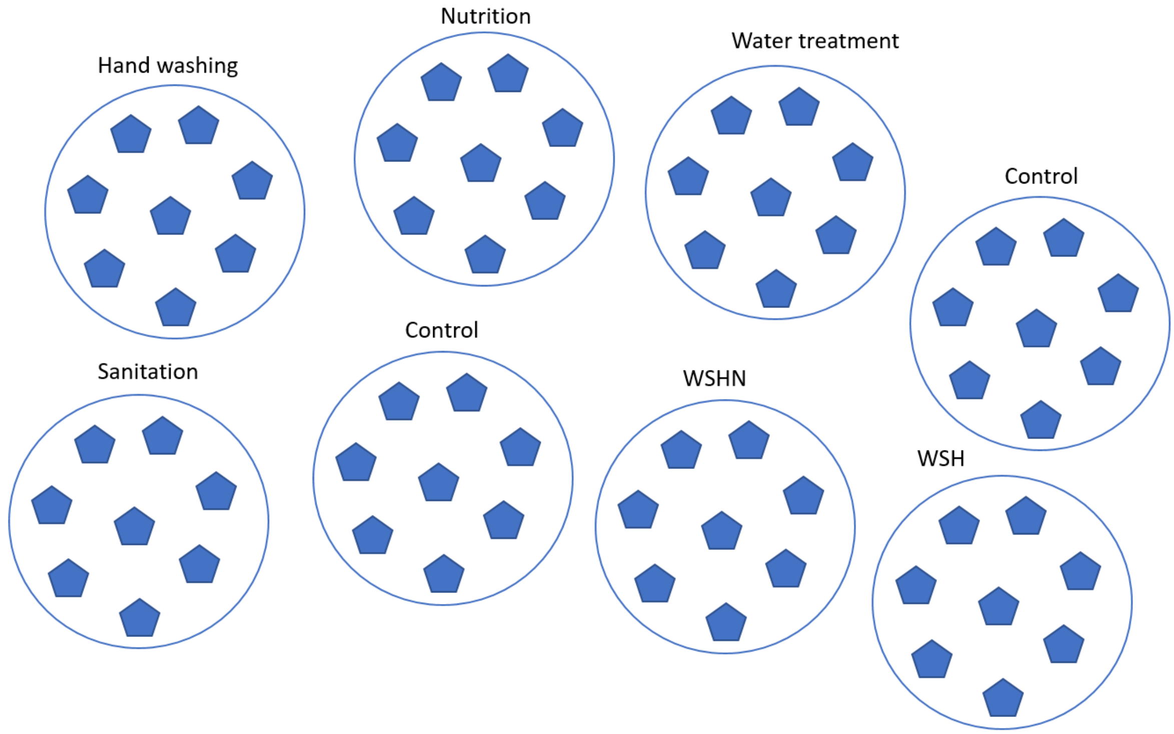


Figure 2.2 provides an overview of the WASH Benefits study design. The interventions will require about 3 months from the baseline survey to deliver. The follow-up rounds are planned for 12 and 24 months after intervention delivery [Source: Arnold et al. 2013] The cluster size in Bangladesh included 8 geographically proximate households with pregnant mothers in their second or third semester

Fig 2.3: The Wash Benefits 'block' comprised of six intervention and two control 'clusters', each of 8 households with a pregnant woman (at enrollment) with 1 km buffer between consecutive clusters; W= water treatment and safe storage; S= sanitation; H= hand washing; N= nutrition; C=control; WSH= water treatment + sanitation + hand washing; N+WSH= nutrition + water treatment + sanitation + hand washing



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Chapter 3: Effect of water, sanitation, hygiene and nutrition interventions on respiratory illness in children in rural Bangladesh: A randomized controlled trial

Abstract

Background: Acute respiratory infections (ARI) are one of the leading causes of morbidity and mortality in young children globally. Overlapping risk factors for respiratory illnesses suggest that combining nutrition and interventions improving water, sanitation and hygiene conditions in resource-poor settings, could lead to larger reductions in childhood illness compared to each component alone. There is little evidence of the direct comparison of the effects of single and combined WASH and nutritional interventions on respiratory illness in young children.

Method: We conducted a cluster randomized trial in rural Bangladesh (ClinicalTrials.gov NCC01590095). We grouped pregnant women into geographic clusters and randomly assigned the clusters to 1) chlorinated drinking water, 2) upgraded sanitation, 3) handwashing promotion, 4) combined water, sanitation and handwashing (WSH) 5) a child nutrition intervention including lipid based nutrient supplements 6) combined WSH plus nutrition or 7) control. The outcome was defined as mothers' reports of cough or difficulty breathing in the past 7 days among children < 3 at baseline, and among children born to the enrolled pregnant women. We followed the closed cohort longitudinally and measured outcomes at 12 and 24 months after initiating the intervention. Analysis was intention to treat.

Results: Compared with children in the control group (P: 8.9%), caregivers of index children reported significantly lower respiratory illness in the water (P: 6.3%, PR: 0.71, 95%CI: 0.53, 0.96), sanitation (P: 6.4%, PR: 0.75, 95%CI: 0.58, 0.96), handwashing (P: 6.4%, PR: 0.68, 95%CI: 0.50, 0.93) and the combined WSH+N arms (P: 5.9%, PR: 0.67, 95%CI: 0.50, 0.90) (Table 3.2). Caregivers of children randomly assigned to the nutrition (7.4%, PR: 0.84, 95%CI: 0.63, 1.10) or the combined WSH arm (P: 8.9%, PR: 0.99, 95% CI: 0.76, 1.28) reported similar prevalence of respiratory illness compared to control households. Caregivers therefore reported lower respiratory illness in the single water, sanitation or

handwashing intervention arms compared to the combined WSH arm (Table 3.2). Pre-specified adjusted analyses resulted in similar effect estimates of interventions on reported respiratory illness in index children.

Conclusion: Water, sanitation and hygiene interventions reduce respiratory illness in young children. The same benefit was observed when water, sanitation and hygiene interventions were successfully integrated with nutrition interventions. Single WASH interventions may be more effective in reducing respiratory illness and should be prioritized with limited resources.

3.1 Introduction

Acute respiratory infections (ARI) are one of the leading causes of morbidity and mortality in young children globally [1,2]. ARI and pneumonia cause majority of hospitalizations and death among children under 5 years of age in Bangladesh [3–5]. Risk factors for pneumonia include low birth weight, malnutrition, crowding, poor air quality, low-income, and poor exclusive breastfeeding rates [3,6]. Poor environmental conditions enable transmission of pathogens and exacerbate infectious diseases contributing to poor nutrition, cognitive deficits and weak immunity in young children [7,8]. Simple interventions such as handwashing with soap have been shown to reduce acute respiratory infection by blocking transmission of respiratory pathogens [9,10]. Studies have shown that improvements in water quality and sanitation may reduce the risk of respiratory illnesses depending on their effectiveness and scale[11,12]. Overlapping risk factors for respiratory illnesses suggest that combining nutrition and interventions improving water, sanitation and hygiene conditions in resource-poor settings, could lead to larger reductions in childhood illness compared to each component alone[13–15]. There is little evidence of the direct comparison of the effects of single and combined WASH and nutritional interventions on respiratory illness in young children. The WASH Benefits study is a community-based cluster randomized trial in rural Bangladesh designed to assess the impact of single and combined water, sanitation, hygiene and nutrition interventions in single and combined interventions on child health.

3.2 Method

Study setting

The study was conducted in rural sub-districts in Gazipur, Kishoreganj, Mymensingh, and Tangail districts of Bangladesh that met the selection criteria. This included areas with low iron and arsenic levels in drinking water, no other ongoing WASH or nutrition interventions and areas not prone to extreme flooding (haor areas). WASH Benefits was conducted by the International Center for Diarrheal Disease Research, Bangladesh (ICDDR,B). It included context specific interventions developed through piloting over 2 years to optimize uptake in rural communities. The technologies and behavioral interventions were delivered through local promoters who were selected from residents of study villages and trained by the project staff. Details of these intervention packages have been published [16].

Study design

We conducted a community based cluster randomized trial designed to assess improvements in water quality, sanitation, hand washing and child nutrition, alone and in combination to rural households in Bangladesh. The study aimed to measure benefits to child health from low cost WASH interventions and nutrition supplements. Details of the study design have been published elsewhere[16]. It included six intervention arms and a double-sized control arm. In Bangladesh, the unit of randomization is a group of compounds that was visited by a single local promoter and separated by at least a 1 km buffer region to minimize the risk of contamination among groups. The drinking water and handwashing interventions were delivered at the household level whereas the sanitation intervention was delivered at the compound level. The nutrition intervention was delivered to the index child, born to enrolled pregnant mothers.

Research assistants screened rural compounds to identify eligible women based on the study's eligibility criteria, which included pregnancy status and iron content in their drinking water. Clusters were defined as eight geographically proximate household compounds that could be visited by a local promoter. Pregnant women and their children who are born within approximately 6 months of the baseline survey were enrolled into this study following written informed consent from the compound head, the pregnant mother, and guardians of children under 3 years. The children born to the enrolled pregnant mothers were considered “index” children. We followed the closed cohort longitudinally and measured primary outcomes at 12 and 24 months after initiating the intervention.

Randomization and masking

Blocks of 8 clusters were randomized into 1) drinking water treatment and safe storage, 2) sanitation, 3) handwashing, 4) combined water + sanitation + handwashing (WSH) 5) nutrition, 6) combined nutrition + WSH and 7) non-intervention control group. The control arm was double sized to improve precision of estimates when compared to multiple arms. This trial was designed as a pair-matched, cluster randomized trial. We enrolled clusters in groups of 8 geographically contiguous clusters and then allocated the clusters to either one of six intervention arms or the double-sized control (Arnold et al. 2013). It is a geographically pair-matched design, because any comparison between two arms is pair-matched within the randomization block. For example, within a randomization block there will be one cluster allocated to the Nutrition arm “matched” to 2 clusters allocated to the control arm. Our inference assumes that clusters are independent units. Masking of the subjects or the data collectors to arm assignment was not possible due to the nature of the interventions, which included distribution of products. The research team who implemented the intervention was separate from the data collection team. The analysis was done using re-randomized uninformative assignments to enable masked statistical analyses from raw datasets. Results were unmasked once statistical analysis was completed.

Data collection

Data was collected at baseline from enrolled mother of the index child at 12 and 24 months after intervention initiation from all enrolled households. Field workers also observed hand washing, sanitation facilities and behavior through participant self report as well as direct observations. The cross sectional survey included demographic information, data on households' hygiene, sanitation, water source and treatment status, as well as household construction and possessions. Child's nutritional intake was recorded using a 24 hour food recall and direct observation of LNS packets in the households.

Trained field workers conducted interviews in the enrolled households with the primary female care giver of the youngest child in the household. They asked them to report whether during the past 2 days and in the past one week, each child under 3 years of age had symptoms of illness including cough, difficulty breathing, bruising or abrasion. We classified acute respiratory illness as having cough and fever or difficulty breathing within 7 days prior to the interview.

Statistical analysis

This was an intention to treat analysis. Respiratory outcome was a secondary outcome of this trial, which was originally powered to detect the relative reduction in diarrhea prevalence and length for age Z score in the study population. Since the nutrition intervention was a child specific intervention we restricted this analysis to index children. Index children were defined as the child born to the enrolled pregnant mother.

We calculated descriptive statistics to characterize the cohort children, their households, and their water, sanitation and hygiene conditions. We calculated the unadjusted prevalence ratios of respiratory disease in index children using a pooled Mantel-Haenszel estimator that stratified by matched pair. We used a generalized log linear regression model to estimate intention-to-treat (ITT) effect of each intervention compared to the control group. To calculate adjusted prevalence rations, pre-specified covariates that were associated with the outcome based on a likelihood ratio test ($p<0.2$), was used to adjust for the association[1]. These covariates included field staff who collected data, month of measurement, household food insecurity, child age, child sex, mother's age, mother's height, mother's education level, number of children <18 years in the household, number of individuals living in the compound, distance in minutes to the primary water source, household roof, floor, wall materials, household assets.

[1] Details are available in the pre-registered analysis protocol (https://osf.io/wvyn4/).

Ethical consideration

The study protocol was approved by human subjects committees at icddr,b (PR-11063), the University of California, Berkeley (2011-09-3652) and Stanford University (25863). Independent data safety monitoring boards in Bangladesh oversaw the trials. This study is funded by a grant from the Bill & Melinda Gates Foundation to the University of California, Berkeley.

3.3 Results

Fieldworkers recruited participants from 5551 compounds used to form 720 clusters of pregnant women. These clusters were randomly allocated to one of six interventions or the double sized control arm. Details regarding participant enrollment, randomization and loss to follow up have been published earlier 16. This trial achieved high adherence to interventions across arms as detected through regular fidelity assessments (Luby et al. 2017, in press). In summary, measures of intervention adherence included presence of stored drinking water with detectable free chlorine (>0.1 mg/L), a latrine with a functional water seal, absence of visible feces on the latrine slab or floor, whether the primary handwashing location had soap, and reported consumption of lipid based nutrient supplements sachets. All measures suggested marked differences from the control group, with adherence over 80% in the single intervention groups and similar uptake in combined intervention groups. Adherence was similar in year one and year two.

The baseline prevalence of respiratory illness in children under three years was similar across arms (Table 3.1). We restricted the respiratory outcome analysis to only index children because the nutrition interventions were child specific. 4747 index children were included in the 12 month follow up (age 0.72 years, sd 0.14), and 4667 children (age 1.87, sd 0.17) were included in the 24 month follow up. Household characteristics were similar across groups at baseline (Table 3.1). The average household had five members. Most households drank water from shallow tube wells (74%) and few households had latrines with water seals (29%). The presence of soap for hand washing was low near latrines (7%) and the kitchen (3%). The design effect of the respiratory outcome in this trial was 1.97.

Compared with children in the control group (P: 8.9%), caregivers of index children reported significantly lower respiratory illness in the water (P: 6.3%, PR: 0.71, 95%CI: 0.53, 0.96), sanitation (P: 6.4%, PR: 0.75, 95%CI: 0.58, 0.96), handwashing (P: 6.4%, PR: 0.68, 95%CI: 0.50, 0.93) and the combined WSH+N arm (P: 5.9%, PR: 0.67, 95%CI: 0.50, 0.90) (Table 3.2). Caregivers of children randomly assigned to the nutrition (7.4%, PR: 0.84, 95%CI: 0.63, 1.10) or the combined WSH arm (P: 8.9%, PR: 0.99, 95% CI: 0.76, 1.28) reported similar prevalence of respiratory illness compared to control households. Caregivers therefore reported lower respiratory illness in the single water, sanitation or handwashing intervention arms compared to the combined WSH arm (Table 3.2). Pre-specified adjusted analyses resulted in similar effect estimates of interventions on reported respiratory illness in index children. The overall prevalence of respiratory illness in intervention and control arms over the two years of follow up is shown in Figure 3.1 and the distribution of the prevalence across each block is show in Figure 3.2. There was no difference in the prevalence of caregiver reported bruising or abrasion between children from the intervention versus the control groups (data not shown). There was some variability in prevalence across the 90 blocks, perhaps due to geographically related factors, as evidenced by an over dispersion factor of almost 2 (i.e. the empirical variance of the prevalence was twice that of the theoretical binomial variance).

3.4 Discussion

Reported respiratory outcomes in children whose households received sanitation improvements, chlorinated drinking water intervention, handwashing intervention alone or in combination along with nutritional supplements (WSHN) was significantly lower than those in randomly assigned control households. Children randomly assigned to nutrition interventions or combined water, sanitation and hygiene interventions did not benefit from lower respiratory illness compared to children randomized into the control arms. We found a significant reduction of reported respiratory illness in combined WSHN households in the absence of a similar impact in WSH arm.

The trial achieved high adherence to interventions. Although respiratory illness is a secondary outcome, the sample size gave us adequate statistical power to interpret that the reduced prevalence in water, sanitation, hygiene and combined WSHN arm was a valid effect. These findings reinforce well known protective effects of handwashing on respiratory illness by interrupting pathogen transmission through hands [10,17–20]. This also demonstrates the effectiveness of the handwashing intervention in this trial, homemade soapy water that was promoted with free handwashing stations and detergent refills near the latrine and the kitchen[21].

Results from studies reporting respiratory illness due to sanitation and water interventions vary [22,23]. These results contribute to the literature that suggest a reduction in respiratory illness in children from sanitation interventions [24]. Water and sanitation interventions can impact respiratory disease through effective reductions in enteric diseases in children[25]. Reduced diarrhea in children protect from subsequent infections including respiratory outcomes such as pneumonia specially in undernourished children [26,27].

Malnourished children are at a higher risk of infection including respiratory illness[28,29]. WASH Benefits delivered lipid nutrient supplements(LNS) for children between 6-24 months while continuing recommended breastfeeding practices while promoting micronutrient rich complementary food[16]. Children in this group were taller and had higher weight for height Z scores than the children in control households indicating better nutritional status (data not shown, Ref: Luby et. al. under review). We did not observe a significant reduction in reported respiratory outcomes in children from households that received nutrition supplements. It is possible we were underpowered to reach the set statistical significance, since point estimate shows that children in the nutrition arm were 18% less likely to have reported respiratory illness compared to the children in control households. An insignificant reduction in care giver reported respiratory illness morbidity in children following lipid nutrient supplements is consistent with results from multiple other studies (Bendabenda et al., 2016; Iannotti et al., 2014; Mangani et al., 2014.). We report a significant reduction when nutrient supplements were delivered in households which also received improved water, sanitation and hygiene interventions. Improving nutritional status of young children may be insufficient to impact respiratory illness in highly contaminated environments.

It is unclear why reported respiratory illness in the combined WSH arm was not different from control households when there are significant reductions in the individual W, S, H arms. Single interventions may be adequate to reduce transmission of respiratory pathogens, providing limited opportunity for combined interventions to exhibit added benefits. Courtesy bias in households that receive interventions are known to inflate health impact when outcome is based on caregiver reported prevalence of disease [33]. Overall, we found no evidence of bias using negative control outcomes in this study (data not shown). Respiratory illness unlike diarrheal disease is less likely to be directly linked to WASH or nutrition interventions by the study respondents. In addition, we found an absence of any impact from the WSH arm suggesting that courtesy bias is not a primary source of this inconsistency. Studies promoting combined WSH packages have reported mixed impact on respiratory infection depending on the effectiveness of the interventions combined and the quality of delivery [34,35]. These results support findings from other studies which did not find additive benefits to child health from combining WSH interventions [36,37]. Reasons why combined interventions fail to show additional effectiveness in reducing morbidity include the possibility of sub-optimal delivery or uptake of behavior change messages and similar levels of courtesy bias compared to single interventions [38]. We did not find evidence of suboptimal implementation of the interventions in both the WSH and WSHN arms, as measured through fidelity indicators collected at regular intervals to track delivery and uptake of interventions (Luby et al. main paper, Mahbub et al.).

The randomization of households was successfully achieved in this trial and household level indicators that maybe associated with respiratory illness in children such as fuel used for cooking or number of rooms to indicate crowding were not significantly different from the control arms. Improved hand hygiene can directly curb transmission of respiratory pathogens in children. Improving quality of drinking water through chlorination and reduced environmental fecal contamination through regularly used sanitation interventions can impact respiratory illness through overall reduction in infections rates and boosted immune functions in young children.

Forthcoming publications will analyze objective markers of inflammation in these children. If we are able to establish association between objective markers of reduced inflammatory load in children who received W, S and H interventions compared to WSH, it will strengthen the argument that the reduction in respiratory illness is valid.

This trial achieved high adherence to water, sanitation and hygiene interventions that is uncommon in large scale programs. These results suggest that water, sanitation and hygiene interventions are effective in reducing transmission of respiratory illness. We successfully implemented combined water, sanitation, hygiene and nutrition interventions but our results do not provide definitive evidence of benefits to combining interventions.

Children with better nutrition remained susceptible to respiratory illness in highly contaminated environment and presented with cough and difficulty breathing. We do not report any additive benefit of combining multiple components of water, sanitation and handwashing in this study. These findings indicate that respiratory illness reduction can be achieved through single low cost interventions that can be scaled to affect large populations.

This study was several limitations. We used a 7 day disease recall may underestimate true disease rates with symptoms that were not severe cough or difficulty breathing [39]. We analyzed the data using two day prevalence and did not find significant differences in findings between arms from that reported here (data not shown). Defining our outcome broadly as cough or difficulty breathing does not allow us to detect changes in more severe respiratory outcomes such as pneumonia. Indeed, this non-specific outcome definition might be picking up illnesses such as asthma, that is also characterized by cough or difficulty breathing in young children. Studies measuring differences in childhood respiratory outcomes especially in younger children should ideally include more frequent collection of symptoms given the epidemiology of respiratory illnesses [40]. However, each data collection round in this longitudinal study spanned a whole year and the comparisons of disease prevalence were made within a cluster randomized design ensuring matched seasonal and geographical effects. We used objective measured of uptake that focused on the availability of hardware and supplies to reflect adherence and quality of intervention delivery. These uptake measures may overestimate actual use. Notably, measures such as structured observations did not suggest higher levels of behavior in the intervention arms (Parvez et al. under review).

3.5 Conclusions

Water, sanitation and hygiene interventions reduce respiratory illness in young children. The same benefit was observed when water, sanitation and hygiene interventions were successfully integrated with nutrition interventions. Single WASH interventions may be more effective in reducing respiratory illness and should be prioritized with limited resources.

Acknowledgments

We appreciate the time of the study participants and the dedication of the field team to achieve the aims of this study. This research was financially supported by Global Development grant OPPGD759 from the Bill & Melinda Gates Foundation to the University of California, Berkeley.

3.6 Tables and figures

Table 3.1: Baseline household characteristics and baseline prevalence of respiratory illness by intervention group, WASH Benefits Bangladesh

%/mean	Control (n=1382)	Water (n=698)	Sanitation (n=696)	Handwashing (n=688)	WSH (n=702)	Nutrition (n=699)	WASH+N (n=686)
Baseline prevalence of respiratory illness							
Cough or difficult breathing	12	13	13	15	13	10	15
Household characteristics							
Maternal							
Age	24	24	24	24	24	24	24
Years of education	6	6	6	6	6	6	6
Paternal							

Years of education	5	5	5	5	5	5	5
Household No. HH members Has electricity Has a cement floor	 5 57 11	 5 61 12	 5 59 12	 5 59 8	 5 61 11	 5 59 9.6	 5 60 10.5
Shared courtyard	69	70	68	72	69	72	67
Sanitation Owned	 54	 52	 54	 54	 53	 54	 534
Concrete slab	95	95	92	93	93	94	94
Water seal	30.6	30.6	30	28	26	31	27
Visible stool on slab or floor	48	53	52	52	33	51	46
Open defecation Children 0-<3	82	85	84	85	79	85	88
Children 3-<8 years	38	37	38	39	38	39	37
Human feces House Child's play area	 8.2 1.5	 9.3 0.9	 8 0.9	 10.2 1.2	 6.9 1.0	 8.3 1.1	 7.2 1.0
Water							
Shallow tube well	75	72	75	70	78	74	74
Stored water treated	48	51	49	50	43	43	48
Hand hygiene							
Has soap close to latrine	7	8	8	5	7	5	6
Has soap near kitchen	3	3	2	2	2	4	3

Table 3.2: Respiratory illness prevalence and unadjusted prevalence differences **among index children: 1 and 2 year follow up combined**

	Index child measurements				
Arm	N	n	Prevalence*	PR† (95%CI) , p val	Adj PR‡ (95% CI), p val
Intervention versus Control					

Control	2288	201	8.78	-	-
Water	1208	76	6.29	0.70(0.55-0.91), 0.01	0.71(0.51,0.98), 0.02
Sanitation	1176	75	6.38	0.72(0.56-0.92), 0.01	0.70(0.52,0.92),0.01
Handwashing	1162	70	6.02	0.68(0.52-0.88), 0.004	0.68(0.48,0.94),0.02
WSH	1194	106	8.88	0.99(0.79-1.23), 0.93	0.99(0.76,1.28),0.98
Nutrition	1159	86	7.42	0.82(0.64-1.10), 0.10	0.84(0.63,1.10), 0.10
WSH+Nutrition	1197	71	5.93	0.66(0.51-0.86), 0.01	0.67(0.50,0.90), 0.01
WSH versus Single arms					
WSH	1194	106	8.88	-	-
Water	1208	76	6.29	0.71(0.53,0.94), 0.02	0.74(0.53,1.05), 0.09
Sanitation	1176	75	6.38	0.72(0.55,0.96), 0.03	0.73(0.57,0.93), 0.012
Handwashing	1162	70	6.02	0.69(0.52-0.92), 0.01	0.66(0.47,0.93), 0.02

*Post intervention measurements in year 1 and 2 combined

†Unadjusted estimates were estimated using a pair-matched Mantel-Haenszel analysis

‡Adjusted for potential pre-specified covariates using pair matched generalized linear model to estimate intention-to-treat (ITT) effects: field staff who collected data, month of measurement, household food insecurity, child age, child sex, mother's age, mother's height, mother's education level, number of children <18 years in the household, number of individuals living in the compound, distance in minutes to the primary water source, household roof, floor, wall materials, household assets.

Figure 3.1: Respiratory illness prevalence in index children by calendar month (combined over two year follow-up period). Individual children were measured only once at each round of follow up; each round took approximately one year. Control and intervention clusters were geographically matched and measured concurrently. The control data series includes on average 191 observations per month (range: 76, 261) and the intervention data series includes on average 591 observations per month (range: 226, 782).

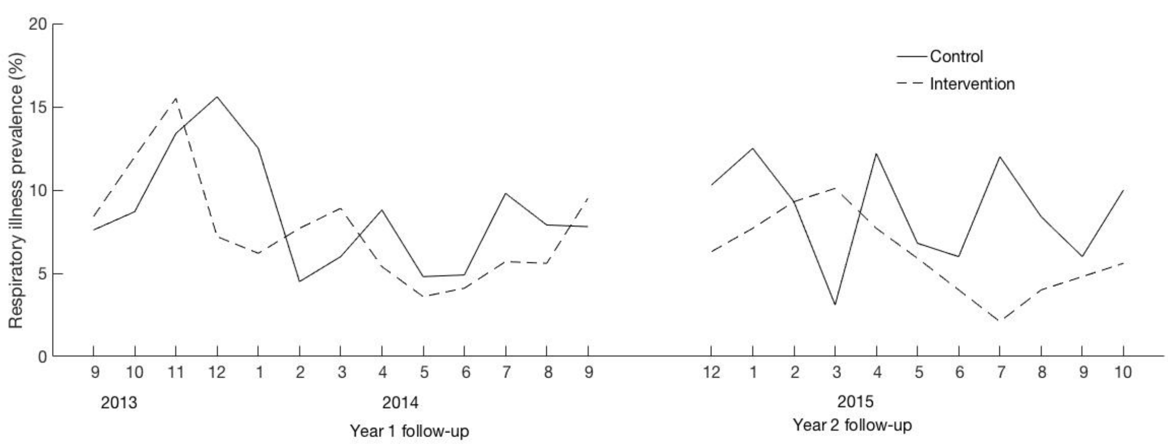

Figure 3.2: Histogram of respiratory illness prevalence in children under 3 years across each block, WASH Benefits Bangladesh (2014-2015)

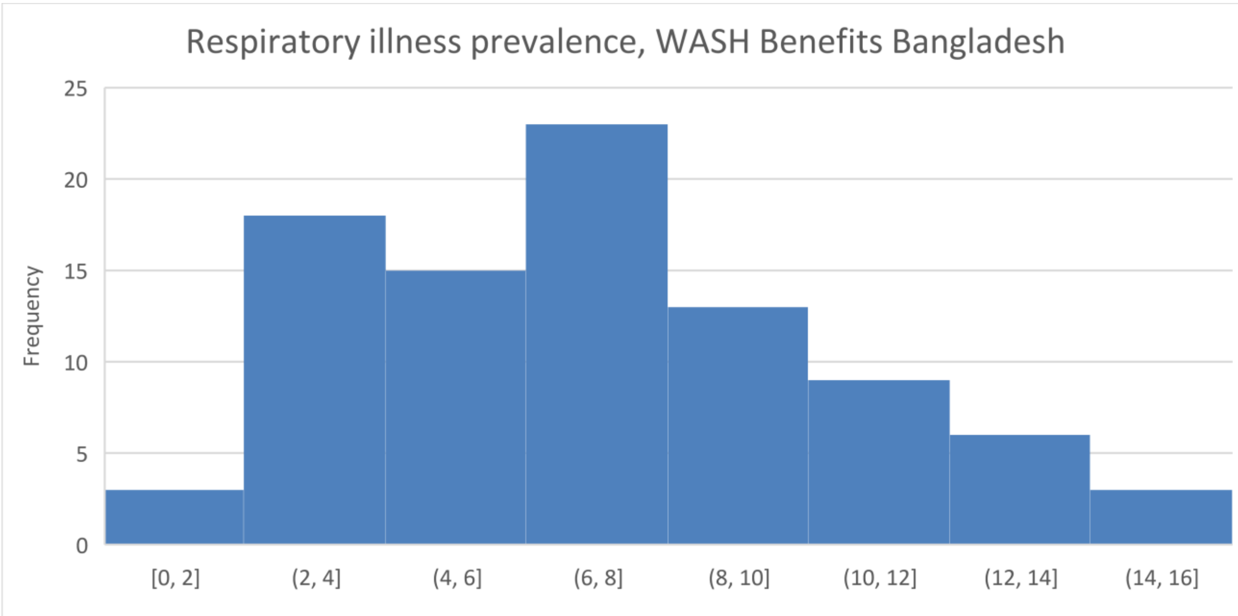

Table S 3.3: Respiratory illness prevalence and unadjusted prevalence differences **among index children: 1 and 2 year follow up combined** with details on covariates adjusted for in each arm

	Index child measurements					
Arm	N	n	Prevalence*	PR† (95%CI) , p val	Adj PR‡ (95% CI), p val	Covariates adjusted for
Intervention versus Control						
Control	2288	201	8.78	-	-	-
Water	1208	76	6.29	0.70(0.55-0.91), 0.01	0.71(0.51,0.98), 0.02	Sex, mom's height, walls, roof, sewing machine
Sanitation	1176	75	6.38	0.72(0.56-0.92), 0.01	0.70(0.52,0.92),0.01	FRA code, sex, electricity, walls, sewing machine, mobile phone
Handwashing	1162	70	6.02	0.68(0.52-0.88), 0.004	0.68(0.48,0.94),0.02	FRA code, sex, wall, sewing machine
WSH	1194	106	8.88	0.99(0.79-1.23), 0.93	0.99(0.76,1.28),0.98	Sex, walls, table, bed, sewing machine
Nutrition	1159	86	7.42	0.82(0.64-1.10), 0.10	0.84(0.63,1.10), 0.10	FRA code, sex, mom's height, walls, table, bed, sewing machine
WSH+Nutrition	1197	71	5.93	0.66(0.51-0.86), 0.01	0.67(0.50,0.90), 0.01	Sex, roof, sewing machine
WSH versus Single arms						
WSH	1194	106	8.88	-	-	
Water	1208	76	6.29	0.71(0.53,0.94), 0.02	0.74(0.53,1.05), 0.09	Walls, bed, chouki/hammock bed
Sanitation	1176	75	6.38	0.72(0.55,0.96), 0.03	0.73(0.57,0.93), 0.012	Walls chouki, motorbike, mobile
Handwashing	1162	70	6.02	0.69(0.52-0.92), 0.01	0.66(0.47,0.93), 0.02	Walls chouki, motorbike, mobile

*Post intervention measurements in year 1 and 2 combined

†Unadjusted estimates were estimated using a pair-matched Mantel-Haenszel analysis

‡Adjusted for potential pre-specified covariates using pair matched generalized linear model to estimate intention-to-treat (ITT) effects: field staff who collected data, month of measurement, household food insecurity, child age, child sex, mother's age, mother's height, mother's education level, number of children <18 years in the household, number of individuals living in the compound, distance in minutes to the primary water source, household roof, floor, wall materials, household assets.

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Chapter 4: Patterns of environmental risk factors in rural Bangladesh: A latent class analysis

4.1 Abstract

Background: Sanitation programs are prioritized by governmental or non-governmental implementers, although recent large scale studies have inconclusive impact on health and nutrition. Fecal-oral pathogens are transmitted through a variety of complex, environmentally mediated pathways that interact with each other and are modified by human behavior. Identifying ways to describe existing combinations of environmental risk factors in low-income populations might lead to more effective targeting of WASH interventions. We sought to identify subgroups to categorize risk factors by examining patterns in water, sanitation and hygiene related characteristics in rural households in Bangladesh.

Method: Field workers interviewed pregnant women from 1382 rural households from 4 districts about demographic characteristics, household income, and observed water, sanitation and hygiene related facilities inside the house and around the courtyard including the latrine, hand washing station and the presence of animals. Model building for latent class analysis (LCA) included decisions regarding WASH indicators and how many classes are needed to represent the data, based on the Bayesian information criterion (BIC). We explored factors associated with these classes including geographic distribution, socioeconomic status and demographic characteristics.

Results: Seven discriminating categorical indicators were used in the latent class analysis including type of latrine, latrine ownership, daily open defecation by child aged 3-8 years, hand washing station, shared courtyard and type of wall and floor. Four subgroups were identified with increasing environmental contamination risk profiles. The classes differentiated between owners of latrines with intact water seals and those with broken water seals. Households without access to any latrines constituted the group with characteristics with the highest risk (4%). Those with high conditional probability of individual toilet ownership (84%) and intact water seals (70%) constituted the group with the lowest risk. Indicators of

risky behavior, especially absence of hand washing stations with soap and water and daily open defecation by children between 3-8 years of age, grouped together to indicate groups with increasing risk of fecal exposure. Differences in housing materials were seen across the classes, where cement floors and brick walls indicated a higher income household compared to those with corrugated iron or mud walls and mud floors.

Conclusion: Distinct sub-populations can be categorized using their household infrastructure and hygiene behavior. Households with distinct latent profiles may benefit from different combinations of water, sanitation and hygiene interventions targeting fecal contamination.

4.2 Introduction

Diseases related to poor access to safe water, sanitation and hygiene education lead to a wide spectrum of health consequences in children, including enteric disease, growth faltering, impaired cognitive development, reduced response to vaccines and reduced immunity to fight infections, increasing the risk of death [1–4]. Fecal-oral pathogens are transmitted through a variety of environmentally mediated pathways that interact with each other and are also modified by human behavior. The efficacy of single water, sanitation or hygiene interventions (WASH) in reducing exposure to fecal pathogen has been established in low-income communities [5,6]. Systematic reviews have concluded while WASH interventions reduce diarrheal diseases, multiple interventions may not have additional impact [5,7,8]. Implementing effective interventions at scale can be difficult[9]. Access to improved sanitation and safe drinking water is still low in low-income countries [10]. Resource intense programs specially in sanitation, continue to be prioritized by governmental or non-governmental implementers despite inconclusive impact of large scale implementation [11,12]. Recent evaluation of sanitation interventions showed improvements in childhood health or growth in resource limited settings like India and Mali are limited and suffer from low uptake due to difficulties in changing existing habitual behaviors [11–13]. To reduce childhood morbidity and mortality, high coverage and uptake of the most cost-effective interventions is required. It is also important to know when uniform interventions are delivered to a heterogeneous population with varying baseline risk factors, whether certain subgroups within the population benefit more from the interventions compared to others. First, such evidence could help to maximize the value of existing resources by shifting expenditures to the most cost-effective interventions. In addition, such evidence could help generate more resources for targeted implementation of simple technologies and behavior change approaches that cost-effectively improve health to those who need it the most. To address this, we sought to identify subgroups of households with common fecal exposure risk factors by examining patterns in water, sanitation and hygiene related characteristics routinely collected in WASH surveys, using latent class analysis, in rural Bangladesh.

4.3 Methods

Study setting and design

This study uses baseline data from the cross-sectional survey from a large cluster-randomized controlled trial of water, sanitation, hygiene and nutrition interventions called WASH Benefits in rural Bangladesh. The design and rationale has been published previously[14]. In summary, these households were enrolled from four districts including villages in Gazipur, Kishoreganj, Mymensingh and Tangail. These rural communities were chosen because of low iron and arsenic content in their drinking water, low risk of flooding and no reported ongoing WASH interventions during enrolment. The WASH Benefits Bangladesh trial enrolled households with pregnant women in their first or second trimester in clusters of eight proximate households. Rural Bangladeshi households usually occur in compounds cohabited by patrilineally linked families. We included data from 1382 households who were randomized into the control arm.

Data collection

Field staff used a structured questionnaire and observations to record demographic characteristics, household materials, possessions, income and observed water, sanitation, hygiene related facilities, and animal presence inside the house and in the courtyard, between May 2012 and July 2013. Informed consent was obtained from the compound head and the mother or guardian of children under 3 years of age in the compound.

Data analysis

Latent class analysis (LCA) is a data reduction tool used to discover subtypes of cases or in this study, households based on their responses to categorical observed variables[15]. It is commonly used in diagnostics to identify disease subtypes, in psychology, marketing, sociology and education. LCA is particularly appropriate for data on the presence or absence of symptoms such as those used in this study. This analysis contrasts with factor analysis, which is also used to study underlying latent structures, and use continuous indicators to produce continuous and usually normally distributed latent variables.

To identify indicators for the LCA, descriptive statistics of all indicators collected were calculated to measure the baseline conditions of water, sanitation and hygiene practices, animal or cattle presence and housing characteristics. Proportions for all categorical variables and medians with inter-quartile ranges were calculated for continuous variables to assess skewness. A subset of variables was chosen to reflect dimensions spanning water source and handling, sanitation including latrine type to child disposal practices, hand washing, and household material indicators that may be associated with child health (Table 4.1). These variables were checked for validity mainly to see how well the indicator captures aspects of desired behaviors and observations (content validity) and reviewed by content experts. Final variables were selected from those with proportions that varied between 10-90% to ensure enough variance across households. We tested the following variables for inclusion in the exploratory latent class analysis given their relevance in the rural setting even though they had low variation: the total number of children under 3 years in the compound, water source, biofuel used in the household, animal feces present in the area where a child spends most time, and cattle presence in the courtyard. We defined adequate sanitation by using three categories: those who reported having no access to a latrine; those with a broken or no water seal and those with intact water seals. We classified hand washing stations into three categories: those who reported not having a specific hand washing place, those that did not have both soap and water together at a specific hand washing place and those observed to have water and any kind of soap including bar/liquid soap and detergent. Courtyards were defined as individual if the household had a separate courtyard; shared if the courtyard was commonly used by more than one household in a compound setting.

Latent class analysis (LCA) was conducted using the statistical software MPLUS 7.8 [16]. As mentioned, LCA is a statistical method that we used to identify distinct subgroups of rural households based on their heterogeneity in observed characteristics captured through categorical water, sanitation, hygiene and household level characteristics. It uses model based clustering of categorical indicators to classify households to their most likely latent class [17]. These mutually exclusive classes are assumed to have conditional independence, meaning that within each latent class, each variables is assumed to be independent [18]. For example, within a latent class the type of hand washing station the household has would be independent of the type of latrine.

LCA uses maximum likelihood techniques to estimate i) the prevalence of each subgroup or latent class in the population and ii) the probability of having a characteristic, given class membership (conditional probabilities) [18,19]. The LCA tests the fit of a two-class model and increases the number of classes until the adding more classes does not improve the representation of the data. To do this, we inspected Bayesian information criterion (BIC), Bootstrapped likelihood ratio test (BLRT) and entropy [20]. Lower BIC indicates better model fits and higher entropy indicates better class separation. BLRT determines whether including additional classes improves the model fit. Secondly, we used non-statistical criteria to inspect model fit data to ensure that the number of classes was conceptually meaningful in the country's context and epidemiologically relevant [20]. Based on the selected model, each household was classified into the class with their highest posterior probability. The class membership was exported to Stata v.12 for further analysis.

We described these subgroups of rural households in Bangladesh according to their sanitary conditions, highlighting which interventions may be most effective. We calculated the proportion of observed indicators of interest and used one-way analysis of variance (ANOVA) and chi-squared tests to assess the association between socio-demographic characteristics related to subgroups identified by the LCA. We used principal component analysis to calculate a household wealth index using assets and housing materials[21,22].

Ethical considerations

All households provided written informed consent. The protocol was reviewed and approved by human subjects review committees International Centre for Diarrheal Disease Research, Bangladesh (icddr,b) and at the University of California, Berkeley.

4.4 Results

Among the 1382 households included in this study, the average age of female caregivers was 24 years with 6 years of education (Table 4.2). The average household size was five. Shallow tube wells (82%) were the primary source of drinking water. Most households did not have any soap or hand washing agent near their hand washing place (77%). Ninety-six percent reported having access to a latrine, 57% of which were privately owned. Open defecation was regularly practiced by children from 3-8 years of age and less so by adults (7.2% in men and 4.5% women).

Twelve categorical indicators with prevalence between 0.1 and 0.9 were included in the latent class analysis (Table 4.2). The total number of children under 3 years in the compound, water source, biofuel used in the household, animal feces present in the area where a child spends most time, and cattle presence variables were removed from the final LCA because they were not discriminating across emerging groups. The seven indicators were contributed to the final LCA model. We compared the fit of latent class models from 2 to 6 classes (Table 4.3). The four class model had the lowest BIC, while the BTLR test showed significant improvement of fit past the 6 class model. Characteristics of the four and five class models were examined closely for legitimacy. Assessing the distribution of indicators given the rural Bangladeshi context, we concluded that the 4-class model which had the lowest BIC represented distinct characteristics across classes. The estimated probabilities of the indicators in the four classes are discussed in the following section (Table 4.4).

Descriptive results

Class A included 153 (11%) households who were characterized with a high conditional probability of individual toilet ownership (84%) with 70% having intact water seals. All households had a specific hand washing place and also have the most observed hand washing stations with any soap (53%), indicating higher handwashing rates[23]. 90% did not report any daily open defecation of child between 3-8 years. 58% had individual courtyards and their housing structures consisted of brick walls (82%) and concrete floors (87%) (Table 4.4). This is the 'most favorable' class, indicative of minimal environmental fecal exposure conditions. It is characterized by individual water sealed toilets with low prevalence of child open defecation, relatively good handwashing facilities, and homes with brick walls and concrete floors.

Class B included 385 (28%) households characterized with a high conditional probability (100%) of individually owned latrines, but with a 68% probability of having a broken water seal. This practice is very common in rural Bangladesh and this LCA differentiated between the latrine owners who would therefore be categorized as having an unhygienic latrine, despite having an individual latrine. The remaining (32%) had an intact water seal. Despite having a specific hand washing place (62%) only 31% had soap at the time of observation. 78% reported no daily defecation by a child 3-8 years in their household. Many of these households had individual courtyards (73%) and their housing structures consisted primarily of corrugated iron (60%) and all mud floors (100%). This "favorable" class among the emerging classes is characterized by individual latrines with broken water seals, low prevalence of child defecation practices and housing with mud floors.

Class C had included the majority, 783 (57%) of the rural households. These are characterized with a high conditional probability of shared latrines (67%) with broken water seals (84%). 11% had no designated place for washing hands and 79% of those with a designated place had no soap present during observation. 95% had a shared courtyard and 34% reported daily open defecation by children 3-8 years old. 98% of these household have a mud floor with 67% corrugated iron and 30% mud walls. This "unfavorable" class reflects the common rural Bangladeshi household, characterized by shared latrines with broken water seals, with mud or corrugated iron walls and mud floors.

Class D has 61(4%), the least number of households. These households do not own or have access to a latrine (100%). 67% of them reported daily child open defecation. 25% had no designated hand washing place and 69% hand washing stations had no observed soap. 77% had a shared courtyard, with both corrugated iron (66%) and mud (31%) walls and all mud floors. This group, likely to have the highest fecal exposure, has the "least favorable" conditions among the groups, characterized by no latrine access, high child open defecation, with shared courtyards, mud or corrugated iron walls with mud floors.

These classes are distinct in their overall household characteristics indicating more environments for higher contamination from Class A to D. These subgroups of households varied significantly with respect to variety of socio-demographic characteristics (Table 4.5). We found that parental education, total monthly income and a principal component score of household assets to indicate socioeconomic status varied and went down from the 'most favorable' to the 'least favorable class. Proxies of economic wellbeing, such as ownership of mobile phones and presence of household electricity were also higher in more favorable classes. There was geographic variation in the classes. Gazipur, the district closest to the capital primarily had the 'most favorable' class (54%), whereas Mymensingh primarily had the least favorable class (77%) (Figure 4.2).

4.5 Discussion

In rural Bangladesh, latent class analysis identified four underlying classes of households based on environmental indicators capturing water, sanitation, hygiene and household characteristics. Latent class analysis is a novel application to group households based on their environmental characteristics. Groups with unfavorable environmental conditions were associated with lower socioeconomic status, income and education.

Categorizing households in a population highlights possibilities of cost effective approaches to interventions, especially if the classes are distinct in their environmental characteristics (Table 4.6). For instance, in Class A households which already have hygienic infrastructures in place, the most effective intervention might be promoting a hand washing agent and station to encourage hand washing at critical times. For class B, upgrading existing latrines to include water seals and promoting hand washing might be needed. Class C might benefit from latrine upgrades, handwashing and additional sanitation technologies such as potties to address open child defecation. Class D households lack access to basic sanitation and hygiene infrastructures. It requires interventions to target multiple fecal transmission pathways but one that prioritizes latrine access. This type of analysis provides the basis for integrated interventions. Given scarce resources, interventions can be prioritized to choose from household or compound based technologies that would effectively target the environment it is being implemented in [24,25].

This study supplements other methodological approaches addressing the need to describe the existing complex combinations of fecal risk factors in low-income populations with multiple exposures [3]. Gensen et al. proposed a hierarchical effect decompositions strategy that groups risk factors into discrete blocks to improve analyses by understanding direct and indirect effects on diarrheal disease [26]. Sima et. al. used exploratory factor analysis to group together risk categories, resulting in latent variables such as household hygiene, food hygiene, drinking water quality indicators etc. and employed analysis strategies to attempt to group risk factors[27]. While they highlight the dominant exposure pathways, latent class analysis is able to group together households with similar risk factors.

With latent class analysis, we posit that the observed environmental conditions are a result of their membership in a latent class or a subgroup where these households' (hygienic or unhygienic) conditions cluster together. These households have similar income, socio-economic status, education and environmental infrastructure. These subgroups may also represent four distinct behavioral patterns. Household conditions provide stable, social and structural conditions that influence habitual practices especially ones like handwashing and defecation [28–30]. Our results reinforce studies that show that people living in more contaminated environments due to poverty and low education, and lack hygienic infrastructure or technologies, also have poorer hygienic behaviors such as handwashing, hygienic water handling and defecation practices [23,27,31,32]. Habitual behaviors may be refractory to common behavior change interventions that focus on information dissemination without addressing environmental cues that trigger and maintain the behaviors [33]. This has implications on the type of behavior change strategy that is implemented to encourage hygienic behaviors. This intersection of poor infrastructure and education and income is included in the contextual factor at the household, individual and habitual levels in The Integrated Behavioral Model for Water, Sanitation, and Hygiene (IBM-WASH) [34].

In addition, studies have highlighted this by discussing that promotion of WASH related behaviors are faced with multiple barriers which make it hard to sustain them over the long term [35,36]. Specifically changing sanitation related behaviors depends on existing environmental characteristics, facilities, resources or behaviors which are not homogenous across households or communities[37,38]. These include difficulty in changing long-established defecation practices, low perceived health consequences as well as poverty related factors which are harder to measure [37,39–43]. Future research should study behavioral patterns in these latent subgroups of households to inform both the infrastructural change and effective behavior change packages.

From a policy perspective, need based prioritization addressing economic and poverty mobility is a key consideration for strategic resource and service allocation [44,45]. Multiple terms are currently used to describe the poor in Bangladesh to portray their household behavior including: the 'absolute poor' to 'hardcore poor' or 'ultra-poor' and those who are 'transient' or 'chronically' poor [46,47]. Each group faces different health risks and vulnerabilities. "Extreme poverty," defined as living on or below the equivalent of $1.25 per day with food insecurity[248]. Majority in this group in Bangladesh are characterized by landless women, but differ in their household characteristics and ability to lift themselves up from their circumstances. It has been highlighted that this group living below $1.25 is heterogeneous, due to

[2] Definitions of "ultra-poor" include those who are living at less than half the $1.25-a-day poverty line, and those who eat below 80% of their energy requirements despite spending at least 80% of their income on food (Lipton et al. 1986)

different socio-economic conditions that contribute to their poverty [49]. BRAC and other NGOs target many of their interventions and programs to the hardcore poor or ultra-poor to maximize their impact [50,51]. Effective targeting and accounting are crucial to pro-poor planning and depend on availability of data to identify groups most in need [45]. These organizations use per capita consumption and participatory wealth ranking by community members are widely used to identify and categorize the poor [46,47,52]. To validate the wealth ranking, program staff conduct with in-person visits to potential members and screen households using a set of standard criteria including number of meals a day, material of their roof to determine which category of ‘poor’ they rank in[49]. BRAC emphasized that this ‘bottom-up participatory involvement and top-down supervision’, aims to successfully identify ultra-poor so that resources ‘are not wasted on those who could benefit from a less costly intervention’[49]. The latent classes identified in this analysis that focuses on environmental risks and includes indicators such as improved latrines, household roof/floor materials and observations of hand washing place, may suggest new ways to target interventions by BRAC and other NGOs to improve health.

To summarize this study’s novel use of latent class analysis has a number of strengths. First, it can be used to understand the underlying subgroups in setting where variations are common. In WASH research, formative studies are often used to tailor interventions to the target group to optimize their uptake [53–55]. These summaries provide insights into structuring research to ensure more aspects of the underlying subgroups are investigated. Second, all indicators included in this analysis are easily and quickly observable, routinely collected in WASH surveys and not prone to misclassification. Third, this analysis did not use any self-reported indicators except daily open defecation by 3-8 years old children. Self-reported behaviors are prone to social desirability bias, although specifically for open defecation by 3-8 years old children we do not expect biased responses given the cultural acceptance of this behavior in this setting [56].

There are several limitations in this study. First, these results are based on cross sectional data and the findings are not externally valid and should not be used to characterize all rural communities in

Bangladesh. However, the subgroups of households provide insights about the differences within rural communities in the study population across especially within districts. Secondly, the latent classes are described using only the indicators used in the analysis. The extent of fecal risk reduced by relative 'favorable' characteristics has not been corroborated with fecal organism exposure or density measurement in this study. Although studies have shown concrete floors, improved latrines etc. have reduced fecal organisms in the household environment [57,58] we must be cautious about drawing causal inferences of health impact from observed descriptive indicators used in this analysis. Further research is needed to assess differences in disease prevalence in latent subgroups. Third, we imposed class membership of the households as an observed variable that, in MPlus, was modelled as latent and a probability. We examined the proportions of key indicators across latent classes and report that they are comparable to the conditional probabilities calculated by the latent class analysis. Fourth, additional key variables may be needed to characterize a rural subset of households which did not vary substantially across this sample, including animal presence, water quality etc., but may be important to consider when planning interventions. Ideally the questionnaire used to collect the indicators for the analysis would be informed by formative research. Further research should include qualitative investigations to validate these subgroups in terms of their environmental infrastructure. Confirmatory qualitative research would include household visits from each class to confirm and explore additional key distinguishing risk factors common to these subgroups households. Further research could evaluate whether households from different latent classes have higher prevalence of diseases, different habitual practices and study if standard interventions achieve different levels of uptake or health impact.

4.6 Conclusion

Analytical approaches such as latent class analysis that incorporates interactions between environmental and socio-economic factors can inform holistic intervention strategies. With limited resources, research to elucidate ways to improve uptake of targeted interventions to improve health may benefit from latent class analysis.

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4.7 Tables and figures:

Table 4.1: Categorical indicators considered for inclsion in latent class analysis, WASH Benefits, Bangladesh

Facilities	Type of latrine - None - Broken water seal - Intact water seal	Soap and water at a designated hand washing place Improved source of water	How many animals of each stay in your compound? - Cattle - Chicken	No. of households in the courtyard Main material of the floor: - Earth - Wood - Cement Main material of walls: - Earth - Corrugated iron (Tin) - Cement
Exposure intensity	Do you share this toilet with other households? Main material of floor of toilet - Mud - Wood - Cement - Tile/Brick	Type of hand washing agent present Hand cleanliness	Do cattle roam free in the compound? Do chickens or other poultry ever go inside your main house?	How many children <3 years are in this household? How many household members do you have?
Observations	Human feces in the area where the target child spends the most time that could be considered open defecation		Animal feces observed: - In/ around the compound where the target child spends the most time	
Practices	Disposal of the feces from your child's last defecation event -Hygienic -Unhygienic	Do you store your drinking water? Do you treat your drinking water in any way?		

Table 4.2: Socio-demographic and water, sanitation and hygiene characteristics of households included in latent class analysis in rural Bangladesh, 2012 (N=1382)

Characteristic	
N=1382	%/mean
Maternal	
Age	4
Years of education	6
Paternal	
Years of education	5
Works in agriculture	3.9
Household	
No. of persons	5
Had children 0-3 years of age in compound	47
Has electricity	57
Fuel used	
Electric/bio gas	0.3
Wood/crop residue/grass	79
Dung cakes	21
Drinking water source	
Shallow tubewell	82
Deep tubewell	15
Hand washing	
Has any soap near a hand washing place	21
Sanitation	
Daily open defecation	
Men	7.2
Women	4.5
Children 8-15	9.7
Children 3-8 years	38
Any latrine facility	96
Owned	57
Concrete slab	95
Functional water seal	31
Visible stool on slab or floor	48
Animal feces where child spends most time	10
Cattle roams free in the courtyard	19
Shared courtyard	70

Table 4.3: Summary of latent class analysis model fit statistics of incremental number of classes, rural Bangladesh (N = 1382)

Classes	df	Entr[1]	AIC	BIC[2]	BLRT(p)[3]	Class prevalence					
						A	B	C	D	E	F
2	23	0.70	12605.007	12725.326	<0.01	402	980				
3	35	0.83	12133.150	12316.245	<0.01	984	337	61			
4	47	0.85	11824.683	12070.553	<0.01	384	783	61	153		
5	59	0.84	11787.678	12096.324	<0.01	365	282	61	542	132	
6	71	0.87	11756.429	12127.851	<0.01	360	106	61	516	276	61

[1]Entropy: higher value indicates greater precision of classification
[2]Bayesian Information Criterion: lower values demonstrate better model fit
[3]Bootstrap Likelihood Ratio Test, tests for incremental model fit, compared with model with one fewer classes

Table 4.4: Estimated probability of environmental indicators across 4 latent classes, WASH Benefits, Bangladesh, 2012

		4 class model[1]			
Entropy=0.85	N=1382	**Class A [Most favorable]**	**Class B [Favorable]**	**Class C [Unfavorable]**	**Class D [Least favorable]**
Parameter	**n(%)**	153(11)	385(28)	783(57)	61(4)
Handwashing station					
No specific place	126(9.1)	0.00	0.07	0.11	0.25
No soap	367(70)	0.47	0.62	0.79	0.69
Soap and water together	289(21)	0.53	0.31	0.11	0.07
Daily open defecation by child 3-8 years					
Yes	406(29)	0.1	0.22	0.34	0.67
No	976(71)	0.9	0.78	0.66	0.33
Latrine					
No toilet	61 (4.1)	0.00	0.00	0.00	1.00
Broken water seal	963(70)	0.30	0.68	0.84	0.00
Intact water seal	358(24)	0.70	0.32	0.16	0.00
Latrine ownership					
None	61 (4.4)	0.00	0.00	0.00	1.00
Shared	571(41)	0.16	0.00	0.70	0.00
Individual	750(54)	0.84	1.0	0.30	0.00
Shared courtyard					
Yes	958(69)	0.42	0.27	0.95	0.77
Wall					
Mud	401(29)	0.06	0.36	0.30	0.31
Tin	813(59)	0.12	0.60	0.67	0.66
Brick	168(12)	0.82	0.05	0.03	0.03
Floor					
Mud	1237(89)	0.14	1.00	0.98	1.00
Concrete	143(10.5)	0.87	0.00	0.02	0.00

1 Four distinct subgroups of rural households were categorized using the latent class analysis. This table ranks the groups/classes with increasing levels of environmental fecal risks (most favorable to least favorable). All the households in the least favorable group do not have access to latrines. In contrast the most favorable group have the highest conditional probability of individual latrines (cprob=0.84) with intact waterseals. Other features are discussed in the results section of the paper.

Table 4.5: Socio demographic characteristic of subgroups of househols following latent class analysis, rural Bangladesh, 2012

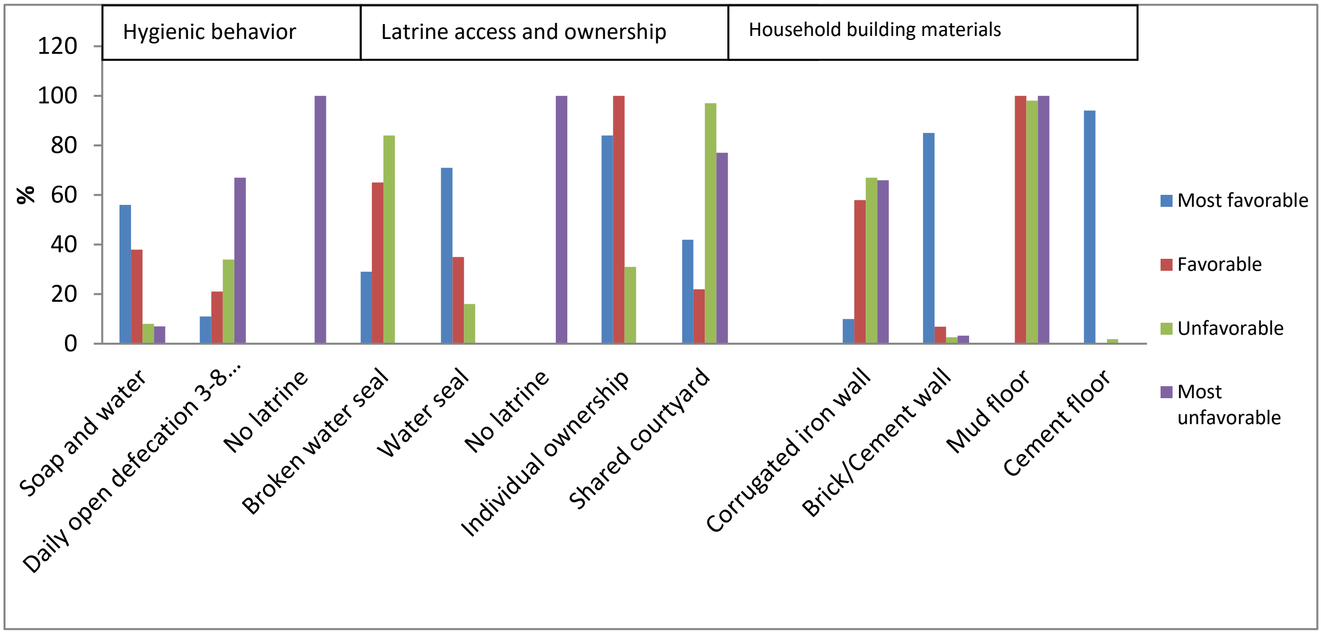
Household Characteristics (mean/%)	**Class A [Most favorable]**	**Class B [Favorable]**	**Class C [Unfavorable]**	**Class D [Least favorable]**	**Significance***
Maternal age	24 (4.8)	24 (5.4)	23.5 (4.9)	24.3 (4.7)	0.29
Mother's education	8.3	6.3	5.6	3.7	<0.001
Father's education	8.1	5.6	4.2	2.1	<0.001
Household head has >5 years of education	74	50	32	9.8	<0.001
Number of households in the compound	1.8 (1.2)	1.7(1.5)	3.1(1.3)	2.8(1.6)	<0.001
Owns mobile phone	98	92	83	64	<0.001
Has electricity	86	62	51	30	<0.001
District					
Gazipur	23	9.8	5.6	5.3	<0.001
Kishorganj	35	25	25	32	
Mymensingh	41	59	64	61	
Tangail	1.2	5.2	5.9	2.1	
Monthly income (USD)					
<125	23	59	82	89	<0.001
125 to 375	57	36	16	12	
>375	20	5.7	2	0	
Socio economic status	79	44	48	0	<0.001
Highest	18	38	38	20	
Middle	2	18	14	80	
Lowest					
Animal presence					
Cattle	65	65	79	72	<0.001
Chicken	30	37	48	48	
Indicators included in the latent class analysis					
Hand washing station:					<0.001
No specific place	0	5.7	11	25	
No soap and water	44	57	81	69	
Soap and water	56	38	8	7	
Daily open defecation 3-8 years					
Yes	11	21	34	67	<0.001
No	89	79	66	33	
Latrine					
None	0	0	0	100	<0.001
Broken water seal	29	65	84	0	

Water seal	71	35	16	0	
Latrine ownership None Shared Individual	 0 16 84	 0 0 100	 0 67 31	 100 0 0	 <0.001
Drinking water deep tube well	30	14	12	17	<0.001
Shared courtyard	42	22	97	77	<0.001
Wall Jute Tin Brick/Cement	 5 10 85	 35 58 6.8	 30 67 2.6	 31 66 3.3	 <0.001
Floor Mud Cement	 0 94	 100 0	 98 1.8	 100 0	 <0.001
*Analysis of variance or chi squared test					

Table 4.6: Summary of key characteristics of the four latent classes and targeted interventions for maximum impact, Bangladesh, 2012

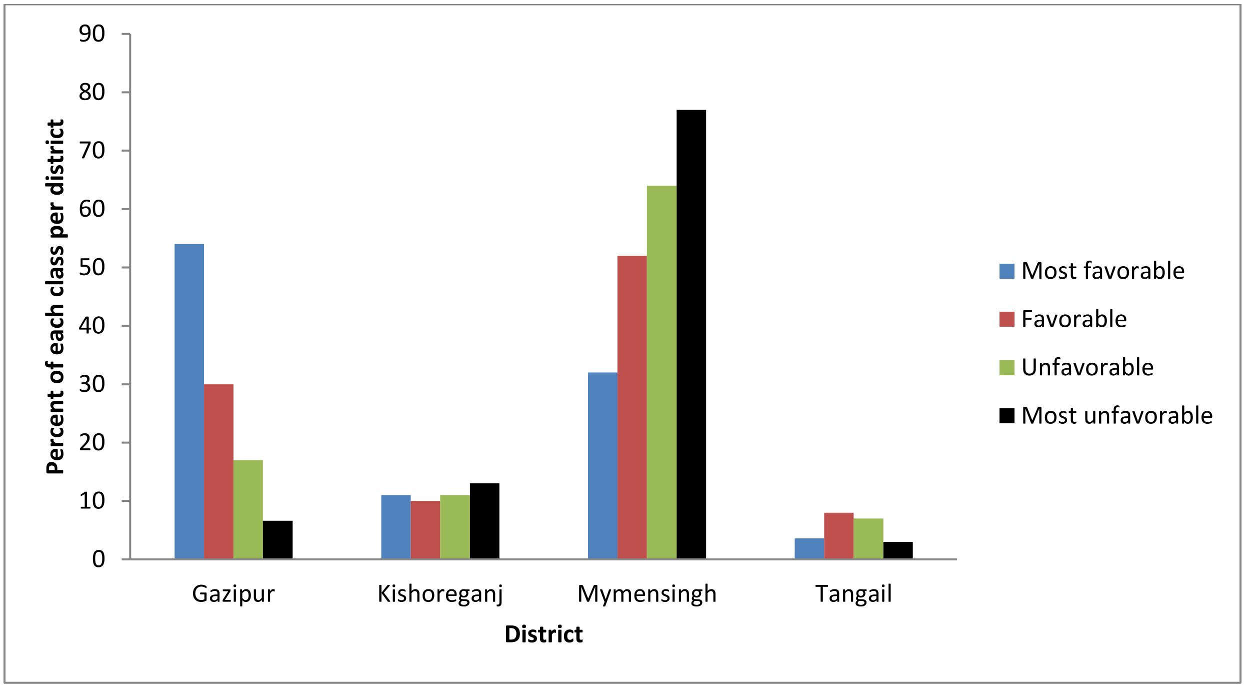
4 latent classes	Key characteristics	Priority interventions
A: Most favorable	Only 53% had a handwashing station (HWS) with soap 70% intact water seals, 84% individual toilet ownership 90% had no daily child open defecation 82% concrete floors	Promotion of hand washing
B: Favorable	Only 31% had soap at handwashing station 68% had broken water seals 100% individual latrines 78% had no daily child open defecation 100% mud floors	Upgrading existing latrines to water seals Promotion of hand washing
C: Unfavorable	84% broken water seals in latrines 67% had shared latrines 79% had no soap at hand washing station 95% shared courtyard 34% had daily child open defecation 98% mud floors	Latrine upgrades Potties or scoops to address open child defecation/animal feces in shared space Handwashing
D: Least favorable	100% has no latrines 67% had daily child open defecation 25% has no HWS and 69% had no soap at HWS 77% had shared courtyard 100% mud floors	Latrines Hand washing Other sanitation technologies

Figure 4.1: Conditional probability of each characteristic of the four latent classes, rural Bangladesh, 2012



The proportion of each characteristic in each latent class is graphically shown in Figure 4.1. The most favorable class The 'most favorable' class has the largest proportion of soap and water at hand washing station, lowerst daily open defecation by child 3-8 years; individual water sealed latrine and brick walls and concrete floors. The 'least favorable' class has low proportions of soap at the hand washing station, high reported open defecation by children, no access to latrines, mud walls and floors.

Figure 4.2: Distribution of the four latent classes across districts, WASH Benefits, Bangladesh



This graph shows which district the households from each class were located. 54% of the households in the most favorable class is in Gazipur, the district closest to the capital and a high density of suburban areas. 77% of the households from the most unfavorable group were from Mymensing, a predominantly rural district.

4.8 References

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Chapter 5: Effect of water, sanitation, hygiene and nutrition interventions on childhood illness across latent subgroups of environmental risk factors in rural Bangladesh

Abstract

Introduction: Households with varying sanitary environments most likely require different sets or intensity of specific interventions both in terms of infrastructure and behavior to effectively reduce contamination levels.

Methods: We nested our study within the WASH Benefits Bangladesh trial, a community-based cluster randomized trial in rural Bangladesh. The study enrolled 5551 households over four districts. We used latent class analysis to categorize the enrolled rural households in WASH Benefits Bangladesh into sub-groups using environmental indicators to assess whether the impact of their interventions on child health varied across classes.We used the latent classes to explore two aims:

1. To determine if latent classes were associated with childhood diarrheal and respiratory illness in young children. We hypothesized that children from households in classes indicative of higher contamination would have relatively higher prevalence of childhood illness compared to those households with lower contamination levels. The main exposure was the latent class membership, expressed as a categorical variable ranging from '4-least favorable' to '1- most favorable'. We built adjusted models to explore the association of the diarrheal and respiratory illness with latent class membership.
2. To determine whether the single water (W), sanitation (S), hygiene (H), nutrition (N) and combined WSH and WSHN interventions delivered in randomized clusters had differential impact across latent classes. We hypothesized that children from households

in classes with characteristics indicative of higher fecal contamination would have relatively higher reduction of childhood illness from the interventions compared to those households with lower contamination levels. The main exposure of interest was the randomized intervention provided to the randomized clusters of households.

The main outcome of interest for both aims was diarrheal disease and respiratory illness prevalence in children under 3 years of age.

Results: In an adjusted model we found an increased risk of diarrheal disease in all classes compared to the '1-most favorable' class, notably a 5 fold increase risk of diarrhea in the '4 most unfavorable' group (aPR: 5.22, 95% CI: 1.67, 16.5). We observed impact of interventions in the '3- unfavorable' group', where diarrheal prevalence in target children from the sanitation (PR: 0.57, 95% CI: 0.39, 0.85), handwashing (PR: 0.34, 95% CI: 0.20, 0.58), nutrition (PR: 0.6, 95% CI: 0.41, 0.87) arm were significantly lower than those in control households. Compared to the control households, there was no significant difference in prevalence between caregiver reported diarrheal disease in index children from households in the '1- most favorable' and '2- favorable' groups in any of the intervention arms. Respiratory illness was not associated with latent class membership. In the '3- unfavorable' group, we observed a relative reduction in reported respiratory illness in index children following the water (PR: 0.65, 95% CI: 0.44,0.96), sanitation (PR:0.70, 95% CI:0.49,1.00) and handwashing(PR: 0.68, 95% CI: 0.48,0.96) interventions, consistent with the impact observed in the main study. Children from the '2-favorable' group benefited from a lower prevalence of respiratory illness in the WSH and nutrition (PR: 0.45, 95% CI: 0.28, 0.87) intervention arm compared to the control arm.

Conclusion: Latent classes based on household environmental indicators can identify households with increased risk of diarrheal diseases in young children. Children from relatively more contaminated households demonstrate a larger benefit from interventions than those in less contaminated households. Further research should evaluate the use of latent class analysis to identify households most likely to benefit from environmental interventions in settings of limited resources.

5.1 Introduction

Worldwide, 1 billion people defecate in the open while 2.5 billion people do not use improved sanitation [1]. More than 577,000 deaths occur annually due to poor hygiene and sanitation[2]. Risk factors such as poor water, sanitation and hygiene (WASH) conditions and practices contribute to undernutrition and an estimated half of childhood stunting[3,4]. Nutrition interventions improves growth and immune function while WASH interventions reduce transmission of a variety of human pathogens[5]. Overlapping risk factors for childhood illnesses suggest that successfully combining nutrition and WASH interventions in resource-poor settings, could lead to larger reductions in childhood illness compared to each component alone[6–8]. There is little evidence of the direct comparison of the effects of single and combined WASH and nutritional interventions on respiratory illness in young children. Recent randomized trials that rigorously evaluated interventions to improve sanitation through latrine installations in rural India [9,10] found little if any impact on health outcomes. Low uptake of large scale interventions highlight the variation in the study population that differ in their environments and most likely require different sets or intensity of specific interventions both in terms of infrastructure and behavior to effectively reduce contamination levels [11] .

We nested our study within the WASH Benefits Bangladesh trial, a community-based cluster randomized trial in rural Bangladesh [12].The study enrolled 5551 households over four districts, where widespread fecal contamination through unimproved sanitation, unhygienic child feces disposal and persistent animal feces is common[13,14]. We used latent class analysis to categorize the enrolled rural households in WASH Benefits Bangladesh into sub-groups or latent classes using environmental indicators to assess whether the impact of their interventions on child health varied across classes. In this paper, we used the latent classes to explore two aims:

3. To determine if latent classes were associated with childhood diarrheal and respiratory illness in young children. We hypothesized that children from households in classes indicative of higher contamination would have relatively higher prevalence of childhood illness compared to those households with lower contamination levels.
4. To determine whether the single water (W), sanitation (S), hygiene (H), nutrition (N) and combined WSH and WSHN interventions delivered in randomized clusters had differential impact across latent classes. We hypothesized that children from households in classes with characteristics indicative of higher fecal contamination would have relatively higher reduction of childhood illness from the interventions compared to those households with lower contamination levels.

5.2 Methods

Study setting and design

This study is nested within a large community based cluster-randomized controlled trial to assess the impact on child health and growth of improvements in water, sanitation, hygiene and nutrition interventions called WASH Benefits in rural Bangladesh. The design and rationale has been published previously[12]. In summary, these households were enrolled from four districts including villages in Gazipur, Kishoreganj, Mymensingh and Tangail. These rural communities were chosen because of low iron and arsenic content in their drinking water, low risk of flooding and no reported ongoing WASH interventions during enrollment. The WASH Benefits Bangladesh trial enrolled households with pregnant women in their first or second trimester in clusters of eight proximate households. Rural Bangladeshi households usually occur in compounds cohabited by patrilineally linked families. We included data from 5551 households who were cluster randomized into 1) chlorinated drinking water, 2) upgraded sanitation, 3) handwashing promotion, 4) combined water, sanitation and handwashing (WSH) 5) a child nutrition intervention including lipid-based nutrient supplements 6) combined WSH plus nutrition or 7) the control arm. These households were surveyed for data collection at year 1 and 2. Further details are included in Chapter 2.

Data collection

Field staff used a structured questionnaire and observations to record demographic characteristics, household materials, possessions, income and observed water, sanitation, hygiene related facilities, animal presence inside the house and in the courtyard, between May 2012 and July 2015. The primary respondent was the mother of the youngest child in the household. These households were followed up for a one and two year follow-up for illness measurements in children under 3 years of age. Informed consent was obtained from the compound head, mother and guardian of children under 3 years of age in the compound.

Outcomes

For the first aim, the main exposure was the latent class membership, expressed as a categorical variable ranging from 'least favorable' to '1- most favorable'. These classes were defined using latent class analysis described in the following section. The main outcome of interest for both aims was the disease prevalence in children under 3 years. The main exposure of interest for the second aim was the randomized intervention (W, S, H, N, WSH, WSHN) provided to the randomized clusters of households. For outcomes of interest, diarrhea was defined as mother's report in the preceding 7 days of >3 loose or watery stools within 24 hours or >1 stool with blood. Respiratory illness was defined as a cough or difficulty breathing in the past 7 days. The trial was powered to detect a relative reduction of 30% in diarrhea and a 20% reduction in respiratory illness in children less than 3 years, from expected 10% prevalences in the control group [12,13].

Data analysis

Latent class analysis

We used latent class analysis (LCA) to identify the main exposure of interest in this study, grouping households in subgroups according to their patterns of fecal exposure risk variables. We inspected Bayesian information criterion (BIC) to guide optimal class selection [15]. Lower BIC indicates better model fit and higher entropy indicates better class separation. Secondly, we used non-statistical criteria to inspect model fit data to ensure that the number of classes was conceptually meaningful in the country's context and epidemiologically relevant [15]. To do this we described the classes using the variables used in the LCA to look at the differences in each new class added. If the new class did not represent characteristics that indicated substantial changes in fecal risk, we chose the lower number class solution to preserve distinct classes. Based on the selected model, each household was classified into the class with their highest posterior probability. The class membership was exported to Stata v.12 for further analysis. LCA was conducted using the statistical software MPLUS 7.8 [16].

Aim 1: To determine association of childhood illness with latent class membership

We used cross sectional data from the baseline survey for this aim. The main exposure was latent class membership of households with children under 3 years of age at baseline; the main outcome was diarrhea or respiratory illness. For each outcome we investigated, we identified potential confounders from different domains including socioeconomic status, demographic characteristics, WASH and household level indicators as factors that were predictive of the childhood illnesses and also likely to affect the exposure of interest. In multivariable models, we included covariates that were associated with the dependent variable at the $p<0.2$ level in bivariate analyses. Potential confounders included socioeconomic status, parents' years of education, type of water source, the number of children in the household, hygienic disposal of child feces, hand cleanliness of mother and child, the number of rooms in the household and presence of animals in the courtyard. We used principal component analysis to calculate a household wealth index using assets and housing materials[17,18]; this index was used to control for socioeconomic status as a potential confounding covariate. We used Stata version 13.0 for this analysis.

Aim 2: Impact of interventions on child health in households from different latent classes

For this aim, we conducted a stratified analysis to evaluate whether the effect on diarrheal and respiratory illness in children varied in intervention versus the control households across each latent class. These latent classes were defined using data from 5551 households enrolled at baseline. We assumed that the households did not change their risk categories over the study duration.

We calculated descriptive statistics to characterize the cohort children, their households, and their water, sanitation and hygiene conditions across intervention arms. We combined all disease measurements over 2 years of follow-up to calculate the prevalence illness in index children aged less than 3 years. We calculated unadjusted prevalence ratios (RR) using generalized log-linear regression model with robust standard errors to account for the clustering of WASH Benefits Bangladesh households [19]. These results have been reported in detail elsewhere (Luby et al. *submitted*, Respiratory outcomes in Chapter 2).

Ethical considerations

All households provided written informed consent. The protocol was reviewed and approved by human subjects review committees International Centre for Diarrheal Disease Research, Bangladesh (icddr,b) and at the University of California, Berkeley.

5.3 Results

We collected health data from 5551 households the control arm over 2 years. The children had a mean age of 1.3 years (SD=0.29). At baseline, 54% of households owned their latrines and 29% had a functional water seal. Most households (74%) collected their drinking water from shallow tube wells. Open defecation was common in children under 3 years (85%) and in children 3-8 years old (38%). Household characteristics were similar across arms (Table 5.1). This trial achieved high adherence of all interventions (>80%), as evidenced by periodic objective fidelity measurements (Rahman et. al. submitted).

Latent class classification

The LCA model analyzed seven binary variables to establish the underlying latent classes (for more details see Chapter 3). The lowest BIC in the latent class analyses was in the six class solution (Table 5.2). We analyzed the difference in characteristics between the 4-6 classes to assess if they are conceptually meaningful in the rural Bangladeshi context. The 4 class solution was chosen to represent meaningful distinct classes compared to the models with more classes. Additional classes led to smaller classes with minor changes in characteristics that made differences between classes less obvious. Comparisons of characteristics with five and six class solutions are included in the supplementary materials (See S 5.8).

The 4 class solution distinguished a '1- most favorable' (n= 597, 11%) group which has households with high individual latrine ownership (82%) with the most water-sealed latrines (intact 25% and broken 70%) (Table 5.3). These households also had high probability having soap and water at a hand washing place, brick walls (82%) and concrete floors (87%). The second '2- favorable' class (n=1228, 22%) was characterized by individual latrine owners (99%) with broken water seals (70%), relatively high probability of having soap and water at a hand washing place (31%) and corrugated iron walls (53%) and mud floors (100%). The 'unfavorable' group (n=3476, 63%) had mud-floored households with mostly shared latrines (67%) with broken water seals (83%) and low probability of soap and water at hand washing places (12%). The '4- least favorable' group (n=251, 4.5%) consisted of households who did not have any latrines and defecated in the open. These households typically had mud floors and 68% did not have a designated hand washing place.

Aim 1: Association of childhood illness with latent class membership

Data from the baseline survey was used to evaluate the differences in disease prevalence in young children across latent classes. This yielded 3675 households with 3658 children with a mean (sd) age of 1.62(0.83) years. The distribution of children across the latent classes is shown in Table 5.4.

The reported diarrhea prevalence in children under 3 years increased from households in the '1-favorable' class (2.4%) to those with less favorable sanitary conditions in the favorable, unfavorable and least favorable groups (5%, 5.5% and 7.9% respectively). In bivariate analyses, diarrhea prevalence was significantly higher in the '3-unfavorable' (PR: 2.27, 95% CI: 0.99, 5.23) and the '4-least favorable' (PR: 3.24, 95% CI: 1.26, 8.39) group compared to the '1-most favorable' group. Hand cleanliness of the mother, number of households in the compound and the child’s age were all significantly associated ($p<0.2$) with diarrheal disease and was included in the final model (Table 5.4). The adjusted model showed an increased risk of diarrheal disease in all classes compared to the ‘1-most favorable’ class, notably a 5 fold increase risk of diarrhea in the ‘4 most unfavorable’ group (aPR: 5.22, 95% CI: 1.67, 16.5). This association held even when additionally adjusting for socioeconomic status in the final model, but led to wider confidence intervals.

Reported respiratory illness in children under 3 years in the ‘1-most favorable class’ was 11.2% compared to those with less favorable sanitary conditions in the favorable, unfavorable and least favorable groups (14%, 13%, and 16% respectively). Respiratory illness was associated with a higher risk in less sanitary latent classes in bivariate analysis although this association was not significant (Table 5.5). Hand cleanliness of mother, the number of under three children in the compound, the child’s age, parent’s education and socioeconomic status were significantly associated with respiratory illness in bivariate analyses ($P<0.2$), and were included in the final model. The final model showed again no significant association of respiratory illness with latent classes. The risk of respiratory illness, however, decreased with increasing age in years (aPR: 0.82, 95% CI: 0.73, 0.92).

Aim 2: Impact of interventions on child health in households from different latent classes

Our results follow the analysis of the direct impact of the interventions on child health from the WASH Benefits Bangladesh trial. For context the results are summarized below:

The impact of interventions on diarrheal disease prevalence across randomized arms is discussed in an upcoming paper under review for publication (Luby et al.; submitted). In summary, compared with children in the control arm, reported diarrhoea prevalence was lower among children receiving sanitation (4.08%; prevalence ratio, PR: 0.64, 95% CI: 0.45, 0.89) handwashing (2.758%; PR 0.43, 95%CI: 0.29, 0.63), combined WSH (4.52%; PR 0.70,95% CI: 0.50, 0.99), nutrition (4.0%; PR 0.62, 95% CI 0.44, 0.85) and combined WSH plus nutrition (4.09%; PR 0.64, CI 0.47, 0.87); diarrhoea prevalence was not significantly lower among children receiving water treatment (5.1%; PR 0.80, 95% CI: 0.56, 1.10). The effect on respiratory illness in index children under three years old is discussed in greater detail in Chapter 3. In summary, caregivers reported significantly lower prevalence of respiratory illness in children under 3 years in households that received single water (6.3, PR: 0.70, 95%CI: 0.553, 0.916), sanitation (6.4, PR: 0.72, 95%CI: 0.58, 0.96), handwashing (6.02 PR: 0.68, 95%CI: 0.520, 0.8893) and the combined WSH+N arm (5.93 PR: 0.66, 95%CI: 0.51, 0.85) compared to those in control households (Table 3.2). Respiratory illness in children from households who received WSH and nutrition interventions did not report a lower prevalence of respiratory illness in children compared to children in control households. The single intervention arms were more effective in reducing respiratory illness in children compared to the combined WSH arm.

Impact of interventions on childhood illness across latent classes

We explored the impact of diarrheal and respiratory illness on index children under 3 years in a stratified analysis across latent classes (Table 5.6 and 5.7). The '4- least favorable' class did not demonstrate an impact of interventions on either disease prevalence in index children compared to those in control households, although some point estimates were stronger than for the '3- unfavorable' group. We observed that in this study, the least favorable class was comparitably much smaller than the others, with only 251 households with 401 children. This limited sample size provided the analysis with limited power in this group. If we combined groups 3 and 4, we did not find any changes in the associations discussed in the following sections.

Diarrheal diseases

Prevalence of diarrheal disease increased from 3.5% in the '1-most favorable class' to 6.9% in the '4-least favorable' class. Compared to the control households, there was no significant difference in prevalence between caregiver reported diarrheal disease in index children from households in the '1- most favorable' and '2- favorable' group in any of the intervention arms. However, in the '3- unfavorable' group', diarrheal prevalence in index children from the sanitation (PR: 0.57, 95% CI: 0.39, 0.85), handwashing (PR: 0.34, 95% CI: 0.20, 0.58), nutrition (PR: 0.6, 95% CI: 0.41, 0.87) arm were significantly lower than those in control households, consistent with the impact observed in the main study. Estimates in the WSH (PR: 0.7, 95% CI: 0.47, 1.03), WSH and nutrition (PR:0.72, 95% CI: 0.5,1.04) arms were similar to the main effects observed in the trial but failed to reach significance (Table 5.6).

Respiratory illness

Respiratory illness prevalence was higher in the '1-most favorable class' (8.4%) compared to the '4-least favorable' class (6.5%). Compared to the control households, there was no impact of the interventions on respiratory illness in the children from the '1- most favorable' households. In the '2- favorable' group, children from the WSH and nutrition arm reported lower respiratory illness (PR: 0.49, 95% CI: 0.28-0.87) compared to those in control households. We observed a relative reduction in reported respiratory illness in index children following the water (PR: 0.65, 95% CI: 0.44,0.96), sanitation (PR:0.70, 95% CI:0.49,1.00) and handwashing(PR: 0.68, 95% CI: 0.48,0.96) interventions in the '3- unfavorable' group, consistent with the impact observed in the main study. Children from the '2-favorable' group benefited from a lower prevalence of respiratory illness in the WSH and nutrition (PR: 0.45, 95% CI: 0.28, 0.87) intervention arm compared to the control arm (Table 5.7).

5.5 Discussion

Globally, diarrhea and respiratory illness constitute the majority of childhood mortality and morbidity especially in low-income countries like Bangladesh [20]. Results from WASH Benefits Bangladesh showed that single sanitation, hygiene, nutrition interventions can be effective in reducing diarrhea prevalence in young children. Reductions in diarrhea were also seen when delivery was combined in WSH or WSH and nutrition packages. Respiratory illness prevalence could be reduced using single water, sanitation, and hygiene interventions and also when combined in a WSH and nutrition package. Impact of these interventions on respiratory illness is discussed in Chapter 3; impact on diarrheal disease prevalence is further discussed in a forthcoming paper (Luby et. al, in review).

In this study, we explored the impact of these interventions within latent classes indicative of sanitary conditions and found that these associations were significant, only in the '3-unfavorable' group and not in more sanitary classes. This supports the hypothesis that these interventions were most effective in unsanitary households, where the high contamination levels were adequately reduced to impact disease prevalence. To elaborate, the '3-unfavorable' sub-group of households had mud floors, shared latrines (67%) with broken water seals (83%) and low probability of soap and water at hand washing places (12%). These households contrast significantly to the '1-most favorable' group characterized with private (82%) water sealed (66%) latrines, hygienic hand washing stations (55%) in households with concrete floors (87%). The significant effect measures in the '3-unfavorable' subgroup support that contaminated environments that enable transmission of pathogens benefits from WASH interventions more significantly than those with cleaner environments. This hypothesis was supported in our adjusted analysis, where compared to the '1-most favorable' group, we saw an increase in relative diarrheal disease in the subsequent less sanitary groups indicating environments more conducive to diarrheal diseases. The cleaner classes of households provided less opportunity to interrupt pathogen transmission giving the analysis less statistical power to demonstrate that interruption.

A study in rural Bangladesh defined cleaner and more contaminated households using three basic indicators: clean drinking water, improved sanitation facility and a hygienic handwashing place [21]. Young children living in cleaner households were found to have improved measures of gut functions, lower parasite infections and improved growth compared to children from more contaminated households. Further research can conduct similar assessments in households categorized using latent class analysis. Reviews have emphasized the limitations of crude 'improved/unimproved' categorizations for sanitation often used in large surveys [22]. Studies have indicated that it is likely that households that differ in their environments would benefit from targeted interventions that effectively impact dominant fecal pathways [11,23]. This study adds to the literature of approaches that have attempted to group risk factors, using techniques such as the hierarchical effect decomposition strategy, to analyze the direct and indirect effects on diarrheal diseases including those through aspects such as socio economic status [24]. In our analysis, we found diarrheal disease were associated with latent classes adjusted for socioeconomic status, indicating that these latent classes capture environmental household level conditions that contribute to the risk of enteric diseases irrespective of their socio economic status.

This study has several limitations. First, we used caregiver reported symptoms to estimate disease prevalence which makes it prone to courtesy bias [25]. However, we found no evidence of bias using negative control outcomes in this study since caregiver reported bruising or abrasion was not different between intervention and control households (Luby et al. submitted). Secondly, we used the 5551 households at baseline to categorize the households into subgroups using latent class analysis for Aim 1. We assumed that through the two years of follow-up, these categories did not change. It can be argued that households invest in infrastructural improvements following key events such as a birth in the family according to heuristic model for teachable moments[26,27]. Future studies can document how frequently households undergo infrastructural improvements following key events to improve health outcomes. Third, the distribution of households across latent classes yielded a relatively small number of households with the most favorable conditions (591 households; 11%) and the most unfavorable class (251 households, 4.5%). This limited our statistical power to detect effect estimates with confidence in the most unfavorable class in this study. Future studies can intentionally sample households within specific classes to study if interventions or behavior change strategies are more effective in these subgroups. In settings, where open defecation is still very prevalent, such as in rural India, such analyses will allow characterization of this group and aid intervention design and assessments.

Future studies can corroborate differences in environmental exposure with laboratory testing for contamination levels. Geospatial analysis of households from the same latent class can help understand if interventions can be provided in a cost-effective way to target subgroups with specific combinations of risk factors.

5.6 Conclusion

Single interventions of nutrition, sanitation, and hygiene can be effective in reducing diarrheal disease in children. Combined interventions are not consistently more effective in reducing childhood morbidities. Children from relatively more contaminated households demonstrate a larger benefit from interventions than those in less contaminated households. Further research should evaluate the use of latent class analysis to identify households most likely to benefit from environmental interventions in settings of limited resources.

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5.7 Tables and figures:

Table 5.1: Baseline household characteristics by intervention group, WASH Benefits Bangladesh (N=5551)

%/mean	Control n=1382 households	Water n=698	Sanitation n=696	Handwashing n=688	WSH n=702	Nutrition n=699	WASH+ N n=686
Target child age	1.29	1.30	1.30	1.29	1.28	1.29	1.29
Maternal							
Age	24	24	24	24	24	24	24
Education (yrs)	6	6	6	6	6	6	6
Paternal							
Education (yrs)	5	5	5	5	5	5	5
Household							
No. HH members	5	5	5	5	5	5	5
Has electricity	57	61	59	59	61	59	60
Has a cement floor	11	12	12	8	11	9.6	10.5
Shared courtyard	69	70	68	72	69	72	67
Sanitation							
Owned	54	52	54	54	53	54	534
Concrete slab	95	95	92	93	93	94	94
Water seal	30.6	30.6	30	28	26	31	27
Visible stool on slab or floor	48	53	52	52	33	51	46
Open defecation							
Children 0-<3	82	85	84	85	79	85	88
Children 3-<8 years	38	37	38	39	38	39	37
Human feces							
House	8.2	9.3	8	10.2	6.9	8.3	7.2
Child's play area	1.5	0.9	0.9	1.2	1.0	1.1	1.0
Water							
Shallow tube well	75	72	75	70	78	74	74
Stored water treated	48	51	49	50	43	43	48
Hand hygiene							
Has soap close to latrine	7	8	8	5	7	5	6
Has soap near kitchen	3	3	2	2	2	4	3
Disease	n=749	n=353	n=348	n=386	n=409	n=366	n=384
prevalence	5.6	7.7	3.7	6.0	4.4	4.9	5.0
Diarrheal disease	12.3	12.6	13.2	15.1	12.7	10.3	14.5
Cough or difficulty breathing							

Table 5.2: Summary of latent class analysis model fit statistics of each incremental classes, WASH Benefits Bangladesh (*N* = 5551)

Classes	Entropy[1]	BIC[2]	A	B	C	D	E	F	G
2	0.84	50624.195	1262	4290					
3	0.83	48936.919	1048	4248	258				
4	0.85	47806.139	1228	597	3476	251			
5	0.84	47721.603	1278	432	3378	251	213		
6	0.86	47679.695	1674	419	247 2	191	175	246	
7	0.79	47689.510	1659	164	1988	461	334	245	701

[1]Entropy: higher value indicates greater precision of classification

[2]Bayesian Information Criterion: lower values demonstrate better model fit

Table 5.3: Estimated probability of each characteristic in each latent class of households enrolled at baseline, WASH Benefits, Bangladesh, 2012

		4 class model			
Entropy=0.85	N=5551	1- most favorable	2- favorable	3- Unfavorable	4- least favorable
Parameter	**n(%)**	597(11)	1228(22)	3476(63)	251(4.5)
Handwashing station					
No specific place	3897(70)	44	63	79	68
No soap	482(8.7)	1.4	6.3	10	26
Soap and water together	1171(21)	55	31	12	6
Daily child open defecation					
None	3933(71)	89	78	68	30
Latrine					
No toilet	276(4.9)	0	0.4	0.4	100
Broken water seal	3904(70)	34	70	83	0
Intact water seal	1370(25)	66	29	17	0
Latrine ownership					
None	237(4.3)	0	0	0	100
Shared	2338(42)	18	1.1	67	0
Individual	2975(54)	82	99	33	0
Shared courtyard					
Yes	1688(30)	57	81	5.3	23
Wall					
Mud	1559(28)	7.2	40	27	27
Corrugated iron (tin)	3288(59)	11	53	70	71
Brick	703(13)	82	6.6	2.9	2
Floor					
Mud	4967(90)	13	100	90	100
Concrete	583(11)	87	0	1	0

This table includes the frequency of each characteristic in the four distinct latent classes in rural Bangladesh. The least favorable class has no access to latrines, no specific hand washing place, high child open defecation and mud floors. By contract the most favorable class has high levels of individual water sealed latrines with concrete floors inside the household.

Table 5.3a: Distribution of latent classes across intervention arms, Wash Benefits Bangladesh

Latent class (%)	Control	W	S	H	WSH	N	WSHN
Most favourable (11%)	9.4	9.9	12	7.5	10.3	8.5	8.9
Favorable (22%)	15	14	14	13	13.2	15	16
Unfavorable (63%)	70	72	68	70	70	72	70
Least favourable (4.5%)	5.2	3.8	6.7	6.3	6.3	5.3	4.5

This table includes the frequency of each latent class across each intervention arm in Wash Benefits Bangladesh. The distributions of classes are comparable across the arms except a low 7.5% of the most favorable class in the hand washing arm.

Table 5.4: Association of diarrheal disease prevalence in children under 3 years and latent classes of households, rural Bangladesh 2013

N =3657 households with children under 3 years at baseline Model 0	Diarrhea in children <3 years PR (95%CI)
1- Most favorable (n=296 children)	Ref
2- Favorable (n=333)	2.07 (0.76,5.64)
3- Unfavorable (n=2812)	2.27(0.99,5.23)*
4- Most unfavorable (n=234)	3.25(1.26,8.39)*
Model 1- WASH indicators	
Water source	0.79(0.56,1.11)
Hand cleanliness of mothers	1.32(0.95,1.82)*
Hand cleanliness of child	0.92(0.55,1.56)
Hygienic disposal of feces	1.00(0.99,1.01)
Model 2- Household characteristics	
Number of rooms	0.96(0.82,1.12)
Number of people in the household (q012)	1.01(0.95,1.08)
Number of households in this compound (q014)	1.10(1.01,1.12)*
Number of children <3 years (q013)	0.88(0.62,1.24)
Presence of animals in the courtyard	0.63(0.29,1.39
Type of fuel used	0.71(0.43,1.18)
Model 3- Income and demography	
Monthly income	0.95(0.87,1.04)
SES	0.99(0.79,1.24)
Highest	Ref
2^{nd}	1.00(0.69,1.44)
3^{rd}	0.99(0.63,1.56)
Child's age (years)	0.73(0.61,0.88)**
Mother's years of education	0.96(0.78,1.19)
Father's years of education	0.96(0.70-1.15)
Father works in agriculture	1.02(0.75,1.39)
Model 4- Final model	
1- Most favorable	Ref
2- Favorable	4.13(1.28,14.7)*
3- Unfavorable	3.33(1.10, 10.1)*
4-Most unfavorable	5.22(1.67,16.5)**
Child's age (years)	0.75(0.62,0.92)**
Mother's hand were not clean	1.30 (0.94,1.78)
Number of households in the same compound	1.07(0.99,1.17)

*Significant at p-value<0.2
**Significant at p-value<0.05

Table 5.5: Association of respiratory illness prevalence in children under 3 years and latent classes of households, rural Bangladesh 2013

N =3657 households with children under 3 years at baseline	Respiratory illness in children <3 RR (95%CI)
Model 0	
1- most favorable (n=296 children)	Ref
2- Favorable (n=333)	1.23(0.72,2.07)
3- Unfavorable (n=2812)	1.12(0.70,1.81)
4- Most unfavorable (n=234)	1.39(0.73,2.64)
Model 1- WASH indicators	
Water source	0.95(0.73,1.24)
Hand cleanliness of mothers	0.82(0.67,1.01)*
Hand cleanliness of child	0.91(0.62,1.33)
Model 2- Household characteristics	
Number of rooms	0.94(0.83,1.06)
Number of children <3 years	1.21(0.9,1.47)*
Number animals in the courtyard	1.60(0.67,3.80)
Type of fuel used	1.21(0.92,1.61)
Model 3- Socioeconomic status and demography	
Child's age (years)	0.83(0.74,0.93)*
Tertile of SES	1.08(0.96,1.22)
Highest	Ref
2nd	1.24(0.94,1.61)*
Lowest	1.19(0.92,1.53)*
Mother's years of education	0.98(0.87,1.10)
Father's years of education	0.92(0.81,1.04)*
Father works in agriculture	1.15(0.94,1.40)*
Model 5- Final model	
1- Most favorable (n=296)	Ref
2-Favorable (n=333)	1.18 (0.69,1.99)
3-Unfavorable (n=2812)	1.03 (0.63,1.67)
4-Most unfavorable (n=234)	1.29 (0.68,2.42)
SES	
Highest	Ref
2nd	1.19(0.90,1.59)
Lowest	1.10(0.83,1.47)
Hand cleanliness of mother	0.84(0.68,1.03)
Maternal education (years)	1.08(0.92,1.26)
Father's education (years)	0.94(0.80,1.10)
Child's age (years)	0.82(0.73,0.92)**
Father works in agriculture	1.12(0.92,1.40)

*Significant at $p<0.2$
** Significant at $p<0.05$

Table 5.6: Diarrhea illness prevalence and unadjusted prevalence differences **among index children: 1 and 2 years follow up combined**

N=9382 index children					1- most favorable	2- favorable	3-Unfavorable	4- least favorable
Prevalence					36/1023(3.5)	94/2039(4.6)	279/5919(4.7)	28/401(6.9)
Arm	N	n	Prevalence*	PR (95%CI)				
Control	2288	147	6.42	Ref	Ref	-	-	-
Water	1208	61	5.05	0.80(0.56,1.10)	0.29(0.06,1.36)	0.92(0.53,1.59)	0.84(0.55,1.27)	0.58(0.15,2.2)
Sanitation	1176	48	4.08	**0.64(0.45,0.89)**	0.87(0.29,2.62)	0.55(0.25,1.22)	**0.57(0.39,0.85)**	1.1(0.39,3.05)
Handwashing	1162	32	2.75	**0.43(0.29,0.63)**	0.41(0.09,1.91)	0.80(0.40,1.58)	**0.34(0.2,0.58)**	0.81(0.29,2.33)
WSH	1194	54	4.52	**0.70(0.50,0.995)**	0.79(0.23,2.8)	0.80(0.40,1.58)	0.70(0.47,1.03)	0.38(0.08,1.78)
Nutrition	1159	46	3.97	**0.62(0.44,0.87)**	0.90(0.29,2.82)	0.66(0.29,1.49)	**0.60(0.41,0.87)**	0.35(0.09,1.42)
WSH+N	1197	49	4.09	**0.64(0.47,0.87)**	0.48(0.16,1.44)	0.58(0.30,1.14)	0.72(0.50,1.04)	0.23(0.03,1.47)

Post-intervention measurements in year 1 and 2 combined

Table 5.7: Respiratory illness prevalence and unadjusted prevalence differences **among index children: 1 and 2 years follow up combined**

N=9382 index children					1- most favorable	2- favorable	3-Unfavorable	4- least favorable
Prevalence					86/1023(8.4)	152/2039(7.5)	421/5919(7.1)	26/401(6.5)
Arm	N	n	Prevalence*	PR† (95%CI)				
Control	2286	201	8.78	Ref	Ref	-	-	-
Water	1208	76	6.29	**0.70(0.55-0.91)**	1.07(0.52,2.2)	0.67(0.37,1.22)	**0.65(0.44,0.96)**	1.09(0.32,3.78)
Sanitation	1176	75	6.38	**0.72(0.56-0.92)**	0.71(0.32,1.66)	0.89(0.54,1.45)	**0.70(0.49,1.00)**	0.23(0.03,1.52)
Handwashing	1162	70	6.02	**0.68(0.52-0.88)**	0.64(0.24,1.69)	0.62(0.33,1.15)	**0.68(0.48,0.96)**	1.22(0.29,3.05)
WSH	1194	106	8.88	0.99(0.79-1.23)	0.66(0.24,1.69)	1.16(0.76,1.75)	1.03(0.73,1.45)	0.95(0.34,2.68)
Nutrition	1159	86	7.42	0.82(0.64-0.10)	1.31(0.74,2.34)	0.55(0.29,1.05)	0.88(0.63,1.22)	0.87(0.34,2.25)
WSH+N	1197	71	5.93	**0.66(0.51-0.86)**	0.83(0.42,1.63)	**0.49(0.28,0.87)**	0.76(0.53,1.11)	-

*Post intervention measurements in year 1 and 2 combined

5.6 References

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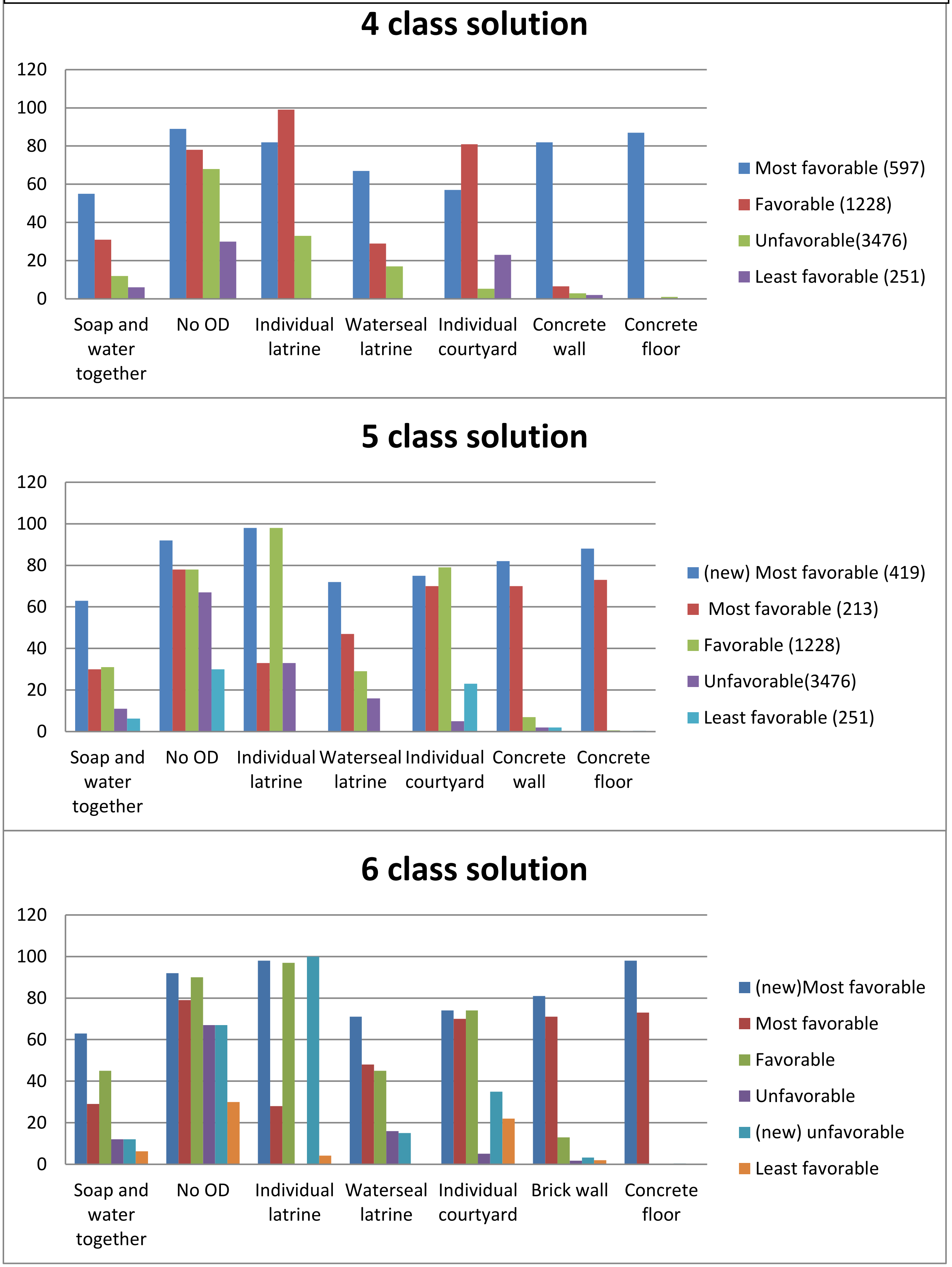
Supplementary materials

Table S 5.1: Differences in characteristics from latent class analysis comparing 4, 5 and 6 class solutions

4 class solution **N=5551** **n(%)**	**1- most favorable-** ***Water-sealed latrine owners with HH concrete floors*** **597(11%)**		**2- Favorable-** ***Individual latrines and courtyards*** **1228(22%)**	**3- Unfavorable-** ***Majority group with broken water sealed latrines*** **3476(63%)**		**4- Most unfavorable-** ***Open defecation*** **251(4.5%)**
Soap and water together	55		31	12		6
No OD	89		78	68		30
Individual latrine	82		99	33		5.5 [93 OD]
Watersealed latrine	67		29	17		0
Individual courtyard	57		81	5.3		23
Concrete wall	82		6.6	2.9		2
Concrete floor	87		0.4	1		0
5 class solution	**432 (8%)**	**213(4%)[1]**	**1278(23%)**	**3378(61%)**		**251(4.5%)**
Soap and water together	63	30	31	11		6.3
No OD	92	78	78	67		30
Individual latrine	98	33	98	33		5.4 [93 open defecation]
Waterseal latrine	72	47	29	16		0
Individual courtyard	75	70	79	5		23
Concrete wall	82	70	7	2		2
Concrete floor	88	73	0.6	0		0.4
6 class solution[2]	**419 (7.5%)**	**191 (3.4%)**	**846 (15%)**	**2175 (39%)[3]**	**1674 (30%)**	**247 (4.4%)**
Soap and water together	63	29	45	12	12	6.3
No OD	92	79	90	67	67	30
Individual latrine	98	28	97	0	100	4.2
Waterseal latrine	71	48	45	16	15	0
Individual courtyard	74	70	74	5.1	35	22
Brick wall	81	71	13	1.7	3.3	2
Concrete floor	98	73	0	0	0.4	0

[1] Class looks similar to '2-favorable' class with relatively less water sealed latrines in households with brick walls and concrete floors; richer households with more broken water sealed latrines
[2] Lowest BIC
[3] All shared latrines; new class based on individual or shared latrines and courtyards

Figure S 5.1: Conditional probabilities of indicators across latent classes, rural Bangladesh



Chapter 6: Discussion

6.1 Summary of study findings

We assessed the impact of water, sanitation, hygiene, nutrition interventions delivered alone and in combination. The implementation of these interventions was closely monitored to sustain high adherence. Findings described in this dissertation will be useful in addressing questions related to WASH intervention evaluation, planning and implementation especially in low-income settings. Analytical approaches such as latent class analysis that incorporates interactions between environmental and socio-economic factors can inform holistic intervention strategies. The distinct latent classes captured sanitary conditions at the household level and were associated with childhood diarrheal disease. Water, sanitation, hygiene and nutrition interventions were more likely to have an impact in households with higher disease morbidity. With limited resources, research to elucidate ways to improve uptake of targeted interventions to improve health may benefit from latent class analysis.

Objective 1: To assess the effect of water, sanitation, hygiene and nutrition interventions on respiratory illness in children in rural Bangladesh

The goal of this objective was to determine if water, sanitation, hygiene and nutrition interventions when delivered individually or in combination using a randomized controlled trial, has any impact on care giver reported respiratory illness in children under 3 years of age in rural Bangladesh. We found that reported respiratory outcomes in children whose households received sanitation improvements, chlorinated drinking water intervention, handwashing intervention alone or in combination along with nutritional supplements (WSHN) was significantly lower than those in randomly assigned control households. Children who received nutrition interventions or combined water, sanitation and hygiene (WSH) interventions did not benefit from lower respiratory illness compared to children randomized into the control arms. We found a significant reduction of reported respiratory illness in combined WSHN households in the absence of a similar impact in WSH arm.

We did not see reductions in respiratory illness in children in the WSH arm. This may be a statistical aberration. Since we ascertained the respiratory outcome using self-reported data from female caregivers of cough or difficulty breathing in children, it is possible the non-specific nature of these symptoms classified conditions such as asthma with acute respiratory illness and reduced the precision around our estimate. However, we except this effect to be uniform across the other arms in the trial, and the geographically matched design randomization allows us to assess the difference in prevalence in children in the intervention arm compared to the control arm. This trial also measured diarrheal disease prevalence and reporting bias in settings where blinding of interventions is not possible such as those with water, sanitation and hygiene interventions. It should be noted that there are alternatives ways to ascertain history of illnesses using immunological assays which now include non-invasive assays based on oral fluid in addition to blood serology[21]. Future research can include these measures to add specificity to the disease prevalence measurements[21].

In conclusion, in this aim we provide further evidence that water, sanitation and hygiene interventions reduce respiratory illness in young children. The same benefit was observed when water, sanitation and hygiene interventions were successfully integrated with nutrition interventions. These findings support that single WASH interventions should be prioritized with limited resources.

Objective 2: To identify latent subgroups that categorize risk factors by examining patterns in water, sanitation and hygiene related characteristics in rural households in Bangladesh

The goal of this objective was to identify underlying subgroups of households in rural Bangladesh, using latent class analysis, to describe distinct environmental risk factors. Latent class analysis identified four underlying classes of households based on easily observable indicators in surveys capturing water, sanitation and hygiene characteristics in rural Bangladesh. Application of latent class analysis is a novel application to group households based on their environmental characteristics. The latent classes varied in key characteristics like access to latrines, ownership of latrines, availability of hand washing materials and household construction materials. Groups with unfavorable environmental conditions were associated with lower socioeconomic status, income and education. Analytical approaches such as latent class analysis that incorporates interactions between environmental and socio-economic factors can inform holistic intervention strategies. With limited resources, research to elucidate ways to improve uptake of targeted interventions to improve health may benefit from latent class analysis.

Objective 3: To determine if latent classes were associated with childhood diarrheal and respiratory illness in young children

The goal of this objective was to assess if childhood illnesses were more common in classes with worst sanitary conditions. We hypothesized that children from households in classes indicative of poor sanitary conditions would have relatively higher prevalence of childhood illness compared to those households with better sanitary conditions. We used cross sectional data from the baseline survey and conducted a latent class analysis to identify 4 subgroups of households with decreasing sanitary conditions. The adjusted model showed an increased risk of diarrheal disease in all classes compared to the '1-most favorable' class, notably a 5 fold increase risk of diarrhea in the '4 most unfavorable' group (aPR: 4.82, 95% CI: 1.46, 15.9). This association held even when additionally adjusting with socioeconomic status in the final model, but led to wider confidence intervals. Respiratory illness prevalence was not associated with latent class membership in adjusted models.

To determine whether the single water (W), sanitation (S), hygiene (H), nutrition (N) and combined WSH and WSHN interventions delivered in randomized clusters had differential impact on childhood illness across latent classes.

The goal of this objective was to determine if the impact of the water, sanitation, hygiene and nutrition interventions delivered in WASH Benefits Bangladesh differed in their health impact across latent classes. We hypothesized that children from households in classes with characteristics indicative less sanitary conditions would have relatively higher reduction of childhood illness from WASH and nutrition interventions compared to those households with more sanitary conditions. There were 4 latent classes in this population, determined at baseline, indicative of increasing environmental risks. For diarrheal diseases, we found reductions in reported diarrheal disease prevalence in index children following sanitation (S), handwashing (H), nutrition (N) and WSH and nutrition (N) interventions compared to control households in the '3- unfavorable' group. This indicates that households with less sanitary conditions are more likely to benefit from interventions that reduce the transmission of pathogens. There was no significant difference in prevalence in index children from households in the '1- most favorable' and '2- favorable' group in any of the intervention arms compared to the control households.

For respiratory illnesses, we observed that children from households in the '2- favorable' group, had lower reported respiratory illness following WSHN arm reported lower respiratory illness (PR: 0.49, 95% CI: 0.28-0.87) compared to those in control households. Children from the '3-unfavorable' group benefited from a lower prevalence of respiratory illness in the W, S, H intervention arm compared to the control arm. Compared to the control households, there was no detectable impact of the interventions on respiratory illness in the children from the '1- most favorable' households.

Due to the small size of the '4- least favorable' class, we did not have adequate power to evaluate morbidity associations in this group. I noted that the point estimates of the impact of the interventions were high as expected in more unsanitary households, but emphasized that the small number of households constituting this group is a limitation when assessing further associations. In settings where open defecation is common, such as in rural India, techniques such as latent class analysis will have important implications. It helps characterize the sub population practicing open defecation and allows interventions to target the concurrent environmental risk factors associated with these practices.

6.2 Implications for policy and practice

These findings may be useful across multiple aspects of WASH intervention policy, implementation and planning. In infrastructure restricted settings, implementation organizations work in collaboration with the government to increase accessibility to improved sanitation and hygienic practices. Scaling up interventions is expensive and requires quality measures to ensure the technologies as well as behavior change communication illicit adequate uptake. Results from WASH Benefits Bangladesh and the objectives in this dissertation underscore that combined interventions targeting several aspects of the contamination may not provide additional reduction in infectious diseases such as diarrhea or respiratory illness in children beyond single interventions. This has implications on scaling up of effective interventions, following successful demonstration of uptake in carefully monitored research studies. Simpler interventions can be implemented better, both because of better management of delivery and through reinforcing a few behavioral messages repeatedly over time to facilitate habit formation. Strategies to identify interventions that can have maximum impact require investigating the dominant risk factors and behaviors prevalent in the specific contexts.

Besides halving number or people without access to improved water supply and sanitation, post 2015 goals include sustainability and equity goals for service delivery[1]. Demand driven services and interventions designed to meet specific needs faced by the target population may lead to more sustainable service delivery and use[2]. Methods to improve targeting of interventions to vulnerable sub-populations are key considerations for strategic resource and service allocation. In low-income countries, especially ones as densely populated as Bangladesh, there are variations in socioeconomic status and demographic characteristics within the same geographic area. These are associated with sanitary conditions of their household environments as well as their hygiene related behaviors, including handwashing and latrine use. Implementation programs need to address existing needs of their target population to achieve maximum impact from their resources. Our findings emphasize the use of latent class analysis to identify subgroups in the population who present with environmental risk factors. Common applications of latent class analysis include diagnostics, marketing, survey research, financial research, sociology, psychology, education and in health sciences where the aim is to identify subgroups within a wider population. Such approaches can improve focus in research by guiding qualitative and formative research to better understand the most vulnerable and in need sub-populations. In addition, our results suggest that different subgroups might benefit from different messages when considering behavior change strategies. Since households with poorer sanitary conditions were associated with lower income, socio economic status and education, it contributes to the contextual factors in which any behavioral promotion will be nested. This has implications especially since the objective of improved practices is not only to alter but to sustain behaviors over time.

Our results demonstrate that current NGOs and other research organizations involved in intervention planning may benefit from focusing efforts and resources strategically. It also demonstrates that assessing the impact of interventions in sub population can explicate whether the interventions benefited certain groups more than others. This can provide further understanding of results that fail to show evidence of improvements in health when the population impact is summarized on average. Looking at differences in uptake can be informative for implementation and donor agencies to revise and/or target their resources.

Effective need based policy prioritizes strategic resource and service allocation [3,4]. Successful targeting is crucial to pro-poor planning and depend on availability of data to identify groups most in need [4]. The poor in low-income countries like Bangladesh, have been described as: the 'absolute poor' to 'hardcore poor' or 'ultra-poor' and those who are 'transient' or 'chronically' poor [5,6]. Health risks vary in across these groups. BRAC and other NGOs target many of their interventions and programs to the hardcore poor or ultra-poor to maximize their impact [7,8]. These organizations use a combination measurement of per capita consumption and participatory wealth ranking by community members to identify and categorize the poor [5,6,9]. Program staff conduct in-person visits to potential members and screen households using a set of standard indicators including material of their roof, floor etc. to determine which category of 'poor' they rank in[10]. BRAC emphasized that this detailed process aims to successfully identify ultra-poor so that resources 'are not wasted on those who could benefit from a less costly intervention'[10]. The latent classes identified in this analysis that focuses on environmental risks and includes indicators such as improved latrines, household roof/floor materials and observations of hand washing place, may suggest new ways to target interventions by BRAC and other NGOs to improve health.

6.3 Strengths and limitations

These studies had a number or strengths and limitations. In objective 1, we analyzed respiratory outcome from a large randomized controlled trial which was designed to allow comparison of water, sanitation, hygiene and nutrition interventions. This trial was able to achieve and demonstrate high levels of adherence (>80%) for the 2 year duration of the study, which is a key strength of the study. The study enrolled 5551 pregnant mothers in this study. This large sample provided sufficient power to compare multiple arms and also allowed exploration of additional objectives with sufficient confidence. Objective 2 and 3 are nested aims within this trial. This enabled us to leverage both the resources and the time invested in the trial to address additional research questions.

For objective 1, we used a 7 day disease recall may underestimate true disease rates with symptoms that were not severe cough or difficulty breathing[11]. Defining our outcome broadly as cough or difficulty breathing did not allow us to detect changes in more severe respiratory outcomes such as pneumonia, which is a major contributor to childhood morbidity and mortality. For objective 2, we demonstrated a novel application of latent class analysis to the WASH field using indicators collected in surveys. We used easily and quickly observable indicators, routinely collected in WASH surveys, not prone to misclassification. Limitations of latent class analyses applied to this research. Specifically, we imposed class membership of the households as an observed variable that was modeled as a probability. To address this, we examined the proportions of key indicators across latent classes and report that they are comparable to the conditional probabilities calculated by the latent class analysis and statistically significant across classes. We were limited by the indicators available to us through the survey to compose the latent classes. We have to be careful to note that additional key variables may be needed to characterize a rural subset of households in other contexts. Characteristics which did not vary substantially across this sample, including animal presence, water quality etc., may be important to consider when planning interventions. We also emphasize that these categorizations of groups of households are not externally valid and should not be used to characterize all rural communities in

Bangladesh. We demonstrated the use of this exercise to identify subgroups of the population and recommend using such exploratory strategies to direct more specialized interventions targeting improved sanitation for maximum impact.

6.4 Future research and next steps

Our results do not provide definitive evidence of benefits to combining WASH with each other or with nutrition interventions. Further research is warranted to study the impact of combined WSH or nutrition interventions on respiratory outcomes in children. These findings indicate that respiratory illness reduction can be achieved through single low cost interventions that can be scaled to affect large populations. Future studies should consider studying the added efficacy of adding individual WASH related interventions to other effective interventions that reduce respiratory illness such as vaccination, improved nutrition and breastfeeding.

We found higher risk of diarrheal disease in latent classes with unsanitary conditions. We are unable to establish biological plausibility of this association directly. Further studies should evaluate the difference in microbial contamination levels in households grouped together with unfavorable sanitary indicators compared to those with favorable conditions. It is important to confirm our latent class analysis findings using actual observation of households each in respective class to confirm the clustering of environmental infrastructure. Confirmatory qualitative research would help understand if these households also engage in risky behavior patterns including low handwashing rates, unhygienic practice or handling of child or animal feces etc. Consistent with previous studies, we emphasized the association of income, socio-economic status and education with the presence of environmental infrastructure such as improved latrines and hygienic hand washing stations. Future follow up studies including observations and in-depth interviews can explore additional key distinguishing risk factors common to these households. Because household conditions influence habitual practices by providing stable conditions, future research can explore whether there are similarities in behavioral patterns that are distinct across latent classes. Promotion of WASH related behaviors are faced with multiple barriers which make it hard to sustain them over the long term [12,13]. Sanitation related behaviors rely on existing environmental characteristics, facilities, resources or behaviors which are not homogenous across households or communities[14,15]. Difficulty in changing long-established defecation practices stem from low perceived health consequences as well as poverty related factors which are harder to measure [14,16–20]. Future research should study behavioral patterns in these latent subgroups of households to inform both the infrastructural change and effective behavior change packages.

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Curriculum Vitae

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EDUCATION

PhD, Department of International Health July 2017
Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD
Concentration: Global Disease Epidemiology and Control; Water, Sanitation, Hygiene, Child Health

Awards

- Research Training on Childhood Infectious Diseases in Bangladesh, Fogarty International Center, NIH, 2014-2017
- Global Health Established Field Placement Travel Award, Johns Hopkins School of Public Health, 2014
- International Health Department Scholarship, Johns Hopkins Bloomberg School of Public Health, 2013-2014
- Aga Khan Foundation's International Scholarship Programme Award, 2013-2015

Masters in Public Health, Department of Global Health May 2009
Rollins School of Public Health, Emory University, Atlanta, GA
Concentration: Global Infectious Diseases, Outbreak Investigation

Awards

- Outstanding Practicum Experience Award, Rollins School of Public Health, Emory University 2009
- Anne E. and William A. Foege Global Health Funding, Rollins School of Public Health, Emory University 2008

Bachelors of Arts, Department of Chemistry May 2007
Bard College, Annandale-on-Hudson, NY
Concentration: Organic Chemistry, Minor: Economics

Awards

- C. T. Sottery Award for excellence in Chemistry, Bard College, 2005-2006
- Distinguished Scientist Scholarship, Merit based full tuition Award, Bard College, 2003-2007

RESEARCH EXPERIENCE

Doctoral Student Investigator July 2015-June 2017
Department of International Health, Johns Hopkins Bloomberg School of Public Health

- Proposed research aims and analyzed longitudinal survey data

- Conducted data quality control, data cleaning, and analysis for large randomized controlled trial
- Prepared manuscripts for submission

Intern, Pneumonia diagnostics, Integrated Development June 2014 – August 2014
Bill and Melinda Gates Foundation, Seattle, USA

- Conducted a literature review of ultra-sonography as a diagnostic for pneumonia in children and in adults
- Developed a health impact model of introducing lung ultrasound as a new diagnostic tool at the health facility level on childhood pneumonia detection and treatment
- Worked with partner modeling and pneumonia experts to combine lung ultrasound as a diagnostic tool into larger comprehensive model
- Understood the organization, administration and funding strategy through meetings with key personnel at the foundation

Graduate research assistant, Institute for International Programs (IIP) January 2014-Jan 2015
Johns Hopkins Bloomberg School of Public Health, Baltimore, USA
• Conduct quantitative data analyses on diarrheal disease care determinants in Bihar and Gujarat in India
• Review existing literature on the effectiveness of rotavirus vaccine and analyze data for new estimates of vaccine effectiveness (published)

Assistant Scientist Sept 2011- Dec 2013
Water Sanitation and Hygiene Research Group, Center for Communicable Diseases
International Center for Diarrheal Disease Research, Bangladesh, Dhaka, Bangladesh
• Coordinated site selection, instrument development and data collection of a large randomized control trial looking at the effect of water, sanitation,hygiene and nutrition interventions on childhood development in Bangladesh
• Coordinated and assisted Principal Investigator with protocol development, revisions and IRB submissions
• Lead a team of one senior research officer, seven research officers and 21 field research assistants
• Coordinated intervention and assessment teams and supervise post intervention data collection
• Coordinated sample collection, transport, storage and training for blood, stool and urine
• Quantitative evaluation of intervention uptake and writing reports
• Data analysis and writing manuscripts

Research Investigator Aug 2009- August 2011
Programme on Infectious Disease and Vaccine Sciences, icddr,b
• Lead and managed the quantitative assessment team of 4 research officers and 10 field research assistants
• Led study site selection, designing and implemented multi component quantitative surveys, supported protocol development, amendments to research and ethical review boards
• Quantitative data analysis for reports to guide project decision making within deadlines

• Contributed towards the behavioral change communication materials for point of water use products, hand washing and sanitation interventions

Graduate Research Assistant Aug 2008- May 2009

The Southeast AIDS Training and Education Center (SEATEC), Emory University

• Customer service satisfaction survey data entry, cleaning and management from affiliated clinics

• Compiled customized reports on clinical indicators using centralized monitoring software CareWare

• Facilitated quality assurance reports and analysis

• Conducted literature reviews

Intern, Malaria Diagnostics, WHO-WPRO May 2008- Sept 2008

The World Health Organization, Western Pacific Regional Office, Manila, Philippines

• Evaluated the WHO-ACTMalaria Expert Malaria Microscopy Retraining and Accreditation Program

• Designed and distributed surveys to assess National Malaria Microscopy Quality Assurance Programs in 14 countries in Western Pacific and SouthnEast Asia Region

• Conducted in-depth interviews and focus group discussions with expert microscopists for case study of malaria microscopy quality assurance in the Philippines for a comprehensive report

• Conducted a comprehensive analysis on current WHO recommended malaria parasite counting method to propose suggestions in the upcoming WHO malaria diagnostics recommendations

Independent Researcher in Green Chemistry Aug 2006-May 2007

Bard College, Annandale-on-Hudson, NY

• Investigated solid phase Wittig Olefination to analyze scope of mechano-chemically induced solvent free reaction conditions

• Synthesized variety of organic compounds (over 15 stilbenes in 3 media) with various substituents for analysis

• Characterized compounds using H-NMR and established Z/E ratios using GC/MS

• Reported novel modification to reaction media to enhance stereoselectivity

PROGRAMMATIC EXPERIENCE

Consultant for The Partnership for Maternal, Newborn and Child Health September 2014- July 2015

World Health Organization, Geneva

- Coordinated a multi stake holder dialogue (MSD) focusing on scaling up information, communication technology (ICT) in Bangladesh
- Conducted stakeholder analysis to design the MSD to effectively address the barriers and challenges to scaling up the national health information system
- Trained as a facilitator to lead stakeholder dialogues with participants from multiple sectors to identify challenges, align priorities and assure accountability for resources and results
- Authored publication for dissemination in peer reviewed journal

Intern June-Aug 2006

Bangladesh Rural Development Committee (BRAC), Dhaka, Bangladesh

• Evaluated community health project in rural village, Niphamari. Bangladesh
• Interviewed over 30 women working as trained health volunteers, physicians and nurses at local clinics in the local language
• Administered surveys regarding program satisfaction and incentive provided for continued volunteer work
• Reported results concerning lacking incentive, encouragement and communication gap at different levels of management of community health workers

TEACHING EXPERIENCE

Teaching Assistant

Johns Hopkins Bloomberg School of Public Health, Baltimore MD

- Large scale program effectiveness and evaluation (2016)
- Global Disease Control- Program and Policy (2015)
- Tutor for Biostatistics I, II and III (2014-2016)

PUBLICATIONS

Peer reviewed articles

Ashraf S, Nizame F A, Islam M, Dutta N C, Yeasmin D, Akhter S, Abedin J, Winch PJ, Ram P K, Unicomb L, Leontsini E, Luby S P, Non-randomized trial of feasibility and acceptability of strategies for promotion of soapy water as a hand washing agent in rural Bangladesh, Am J Trop Med Hyg 2016 16-0304

Lamberti, Laura M.; **Ashraf, S**; Walker, Christa L. F,; Black, R. E., A Systematic Review of the Effect of Rotavirus Vaccination on Diarrhea Outcomes Among Children Younger Than 5 Years, Pediatric Infectious Disease Journal, September 2016, 35, 9 992–998

Ashraf, S., Moore C., Gupta V., CHowdhury A, Azad A. K., Singh N, Hagan D, Labqiue A B, Overview of a multi-stakeholder dialogue around Shared Services for Health: the Digital Health Opportunity in Bangladesh, 2015, 13:74

Pollard S. L, Malpica-Llanos T, Friberg I K, Fischer-Walker C, **Ashraf S**, Walker N, Estimating the herd immunity effect of rotavirus vaccine, Vaccine, Volume 33, Issue 32, 31 July 2015, Pages 3795-3800

N Amin, AJ Pickering, PK Ram, L Unicomb, N Najnin, N Homaira, **S Ashraf**, J Abedin, S Islam, S. P. Luby - Microbiological Evaluation of the Efficacy of Soapy Water to Clean Hands: A Randomized, Non-Inferiority Field Trial, Am J Trop Med Hyg. 2014 Aug;91(2):415-23

Arnold, B. F., Null, C., Luby, S. P., Unicomb, L., Stewart, C. P., Dewey, K. G., Ahmed T, **Ashraf S.**, Colford, J. M. (2013). Cluster-randomised controlled trials of individual and combined water, sanitation, hygiene and nutritional interventions in rural Bangladesh and Kenya: the WASH Benefits study design and rationale. BMJ Open, 3(8). doi: 10.1136/bmjopen-2013-003476

Ashraf S., Huque H., Agboatwalla M., Kenah E., Luby SP, Effect of recent diarrheal episodes on risk of pneumonia in children under the age of 5 in Karachi, Pakistan, Int. J. Epidemiol. 2013;1–7

Ashraf S., Kao A., Hugo C., Christophel E.M., Fatunmbi B., Luchavez J., Lilley K., Bell D., Developing standards for malaria microscopy: external competency assessment for malaria microscopists in the Asia-Pacific, Malaria Journal 2012, 11:352

Peer review activity
American Journal of Tropical Medicine and Hygiene
Pilot and Feasibility Studies

CONFERENCE PRESENTATIONS

Doza S, Islam A., **Ashraf S**., Ercumen A., Pickering A, Kwong L., Das, K., Unicomb L., Luby S., Prevalence and association of diarrheagenic E. Coli detected in stored complementary food and flies caught in the same rural households in Bangladesh, 2015, UNC Water and Health Conference, North Carolina, USA

Islam, M., Ercumen A., **Ashraf S.,** Das K., Kafi M A, Luby S., Unicomb L., Impact of unsafe feces disposal of under 3 years child among households with latrine access in rural Bangladesh, 2015, UNC Water and Health Conference, North Carolina, USA

Ashraf S, Moore C, Gupta V, Chowdhury A, Azad AK, Singh N, Hagan D, Labrique A.B, Overview of a multi-stakeholder dialogue around Shared Services for Health: the Digital Health Opportunity in Bangladesh., mHealth Summit, 2014, Washington DC, USA

Ashraf S, Ghosh P., Unicomb L. Naher S., Ahamed A, Alimojamman M., Luby S P, Can fly counts near latrines indicate sanitation improvements? Findings from rural Bangladesh, 2013, UNC Water and Health Conference, North Carolina, USA

Nizame F., Yeasmin D., Dutta, N., **Ashraf S**., Luby S P, Unicomb L., Can hand sanitizer be a good option for hand hygiene in rural Bangladesh?, 2013, UNC Water and Health Conference, North Carolina, USA

Naser A M, Higgins E M, Arman S, Ercumen A, **Ashraf S**, Rahman M, Luby SP, Unicomb L, Influence of iron and groundwater contamination on residual chlorine of water treated with sodium dichloroisocyanurate (NaDCC) tablets, 2013, Oklahoma Governor's Water Conference, Oklahoma, USA

Ashraf S., Islam M., Alam M., Das B.K., Afroz A., Nizame F., Ram P., Unicomb L., Luby S. P., 2012, Soapy water: a low cost solution for hand washing promotion, American Society of Tropical Medicine and Hygiene, Atlanta, USA.

Ashraf S., Hussain F., Leonstini E., Unicomb L., Luby S. P., 2012, Continued environmental fecal contamination following implementation of sanitation hardware, American Society of Tropical Medicine and Hygiene, Atlanta, USA.

Amin M N, Pickering A., Ram P., Unicomb L., Najnin N., Homaira N., **Ashraf S.,** Abedin J., Islam M S, Luby S P, 2012, Microbiological Evaluation of The Efficacy of Soapy Water to Clean Hands, American Society of Tropical Medicine and Hygiene, Atlanta, USA.

Ashraf S., Unicomb L., Abedin J., Islam M., Alam M., Das B. K., Alim B., Luby S P, 2011, Persistent open defecation in Bangladesh communities with high latrine coverage, American Society of Tropical Medicine and Hygiene, Philadelphia, USA.

PROFESSIONAL DEVELOPMENT

Statistical software skills: STATA , SPSS, MPlus, EpiInfo and ATLAS.ti

Computer skills: Microsoft Office Suite, EndNote, Mendeley

Language: Bengali and English- Bi lingual, Hindi and Urdu (Intermediate conversational)