The impact of a school-based water, sanitation, and hygiene program on health and absenteeism of primary school children

by

Matthew Charles Freeman, MPH

in consideration for the degree of Doctor of Philosophy

July 24th, 2011

Advisor: Thomas Clasen, PhD, McS, JD

London School of Hygiene and Tropical Medicine

Faculty of Infectious and Tropical Diseases

Department of Disease Control

I Matthew Charles Freeman, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.


July 24th, 2011

This thesis is submitted using the "Research Paper Style" rather than the "Book Style" in accordance with Section 15.5 (4) of the LSHTM Research Degrees Handbook.

Acknowledgements

I am indebted to many people for their support throughout this long and arduous process. First and foremost, I need to thank my Dad, sister Julie, and especially my Jewish mother who have tolerated many years of travel to far off places, and have always been enthusiastic supporters of my intellectual pursuits. This thesis is dedicated to you.

I would like to thank my adviser Tom Clasen for his unceasing support throughout the PhD process. Tom went well beyond what was required in order to engage me in his work, was fair and balanced in his feedback, was never obsequious, and provided cool confidence when it was most needed. Rick Rheingans has been my mentor, boss, and friend for many years. I have always appreciated his keen intelligence and his knack for finding the big picture question.

Research is a collaborative effort, and I am thankful to have worked with two talented teams. Many thanks to Robert Dreibelbis, Leslie Greene, and Shadi Saboori at Emory for their friendship, support, and collaboration over the years. At LSHTM, I am grateful to everyone in the Environmental Health Group who made me feel at home, and specifically to Sophie Boisson, Danielle Lantagne, Rachel Peletz, Rachel Pullan, Hugh Sturrock and my other fellow PhD students for not letting me suffer in silence, and who made my time in London a pleasure.

Considerable accolades must be extended to my collaborators at CARE, GLUK, and Water.org. Specifically, I would like to acknowledge the hard work and dedication of Alex Mwaki and John Migele who I have worked with for many years and whose dedication to their work is an inspiration. Imelda Akinyi, Daniel Akoko, Patrick Alubbe, Trish Anderson, Brooks Keene, Peter Lochery, Betty Ojeny, Ben Oketch, Emily Awino, Lily Revashinu Lukorito, Alfred Luoba, Caroline Teti, Liz Were, and Malaika Wright have contributed substantially and substantively to this work.

Freeman, LSHTM July 24th, 2011

Much love, in order of appearance, to Daniel Hopkins, Jeremy Schwartz, Matti Zimbler, Eden Robins, Jen Balkus, Sarah Rosenberg, Andrew Scott, Rachel Blacher, Brooks Keene, and Shadi Saboori who have supported and guided me for years. A huge double-bonus thanks to Nicky Mader for his patience, assistance, and Excel-lent brain.

Sam-bot, thanks for the wags.

Finally, to lovely Bethany for everything, and everything else.

Abstract

This thesis describes research designed to quantify and describe the impact of improved access to school water, sanitation, and hygiene (WASH) access on pupils' helminth infection and diarrhoeal disease and absence from school.

The research was undertaken as part of a five-year cluster-randomized trial in 185 public primary schools in Nyanza Province, Kenya that addressed school WASH impacts, knowledge diffusion, sustainability, and advocacy. One hundred eighty-five schools were randomly selected and assigned to five study arms to receive various water treatment, hygiene promotion, sanitation, and water supply improvements. All pupils at enrolled schools were dewormed at baseline and at two follow-up time points. A total of 11,458 pupils were interviewed over two years to compare rates of school absence, rates and intensity of reinfection with soil transmitted helminths, and risk of diarrhoeal disease.

We found no overall impact of our school-based WASH intervention on pupil absence. However, a domain analysis revealed a substantial and significant reduction in absence for girls attending schools that received WASH improvements. Schools that received a hygiene promotion and water treatment (HP&WT) intervention showed statistically similar reductions to those that received HP&WT in addition to sanitation improvements.

Gender-specific effects were also found for reduced reinfection of soil-transmitted helminth infection. Girls showed a significant decline in

prevalence and intensity of infection with *Ascaris lumbricoides*, while boys showed reduced reinfection for Hookworm. Household WASH characteristics significantly modified the effect of the school-based intervention, revealing potential questions about exposure to fecal pathogens at home and at school.

Schools that received HP&WT and those that received HP&WT plus sanitation improvements showed no reduction in diarrhoeal disease prevalence. However, schools allocated to the water "scarce" research group, which received water supply improvements in addition to HP&WT and sanitation, did show significant and substantial reductions in both prevalence and duration of diarrhoeal illness.

While household-level WASH has been investigated extensively, this is the first comprehensive study to investigate the impact of improved WASH at schools. Overall, our results reveal the important role that school WASH can play in mitigating disease burden and lowering pupil absence. Additional research is necessary to fully explore these issues.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1. Introduction

1.1 Water, sanitation, and hygiene

1.1.1 Diarrheal diseases

Nearly 1.9 million children die each year from diarrheal diseases, accounting for 19% of the total child deaths and 6.3% of the global disease burden (Boschi-Pinto et al., 2008, Pruss-Ustun et al., 2008). Ninety percent of these deaths are among children under 5 years (Pruss-Ustun et al., 2008). Diarrhoea amounts to a greater number of childhood deaths than malaria, AIDS, and tuberculosis combined (Bartram and Cairncross, 2010). Mortality is estimated to account for 90% of the approximately 100 million disability life years (DALYs) associated with diarrhea (Murray and Lopez, 1997). However, even this estimate of the enormous disease burden may actually underestimate the global impact of persistent diarrhoea when other factors are considered, such as stunted growth, long-term cognitive deficits, and educational performance (Guerrant et al., 1999, Guerrant et al., 2002, Moore et al., 2001, Niehaus et al., 2002).

1.1.2 Soil-transmitted helminth infection

Infection from soil-transmitted helminthes (STH) – intestinal nematodes that have a soil-based life cycle – is widespread in the developing world (Bethony et al., 2006). More than 2 billion individuals are infected worldwide with one or more key STHs: *Ascaris lumbricoides* (roundworm), *Trichuris trichiura*

(whipworm), and *Ancylostoma duodenale* and *Necator americanus* (hookworm) (Peter J. Hotez et al., 2006, Crompton, 1999) (Table 2-1).

The majority of the STH-related burden of disease is borne by primary school-aged children between the ages of 5 – 12; it is estimated that over 400 million children of primary school age are infected (Chan et al., 1994, Murray and Lopez, 1996). Helminth infection is responsible for between 12,000 and 135,000 deaths per year and 5 to 39 million DALYs lost per year (WHO, 2004, WHO, 2002, Bethony et al., 2006, Chan et al., 1994). Evidence suggests that intense infections may adversely affect cognitive development in schoolchildren and that even light worm burdens may have a marked impact on the health of young children (Brooker and Bundy, 2008).

Table 2-1: Global estimates of prevalence and number of infections by region. *Chart derived from de Silva (2003)*

World Bank Regions	Infection prevalence (in millions) and %		
	A. lumbricoides	T. Trichiura	Hookworm
Latin America and Caribbean	84 (16%)	100 (19%)	50 (10%)
Sub-Saharan Africa	173 (25%)	162 (24%)	198 (29%)
Middle-East and North Africa	23 (7%)	7 (2%)	10 (3%)
South Asia	97 (27%)	74 (20%)	59 (16%)
India	140 (14%)	73 (7%)	71 (7%)
East-Asia and Pacific	204 (36%)	159 (28%)	149 (26%)
China	501 (39%)	220 (17%)	203 (16%)
Total	1221 (26%)	795 (17%)	740 (15%)

1.1.3 School absence

MDG 2 establishes the goal of universal primary education. Enrollment rates in sub-Saharan Africa rose by 16 percentage points between 2000 and 2007; however, the region still accounts for nearly 50% of children who are not

enrolled in school globally (United Nations, 2010). Even among those pupils officially enrolled in school, there is simply no systematically collected global data that describes how many of these children are actually attending school on a continuous basis. While low enrollment is a well-known problem in low-income settings, specifically among girls, there is also evidence that infrequent attendance also impacts educational attainment (United Nations, 2010). A few studies, primarily from developed countries, have established a link between absence and educational achievement, specifically in literacy and math (Gottfried, 2010, Carroll, 2011).

Absenteeism is also a potential proxy for improvements in disease burden. Treating children in areas of high worm burden with deworming medication has been shown to reduced absence at school (Miguel and Kremer, 2004). A program to improve handwashing with soap reduced absence, ostensibly due to reduction in diarrhea and respiratory infection, though these impacts were not measured (Bowen et al., 2007).

1.2 Access to water, sanitation, and hygiene

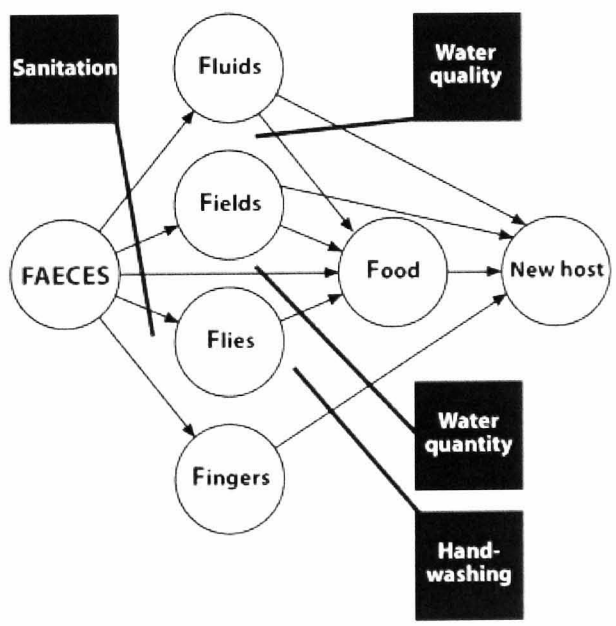
1.2.1 Environmental exposures

The burden of disease from diarrheal diseases and STH infection can be mitigated by reducing exposure to fecal pathogens, specifically by improving access to sufficient and safe water supply, use of sanitation facilities, and proper hygiene behaviors (WASH). Indeed, inadequate WASH are believed to be responsible for 88% of all diarrheal cases and 100% of intestinal

helminth infections (Pruss-Ustun A and C, 2006, Hotez et al., 2006). Of global risk factors, unsafe WASH ranks second in its contribution to disability adjusted life years (DALYs), accounting for over 53 million DALYs representing 6.3% of the global disease burden (World Health Organisation, 2009a).

Improved WASH infrastructure and behaviors act to limit fecal exposure and improve health through a number of key pathways. Proposed in 1958 by Wagner and Lanoix, the five-Fs (Figure 2-1) is a framework still in use to understand how feces in the environment can lead to disease transmission; safe water, improved sanitation, and proper hygiene behaviors are the key primary and secondary barriers for fecal exposure (Wagner and Lanoix, 1958).

Figure 2-1: F-diagram of fecal - oral disease control.

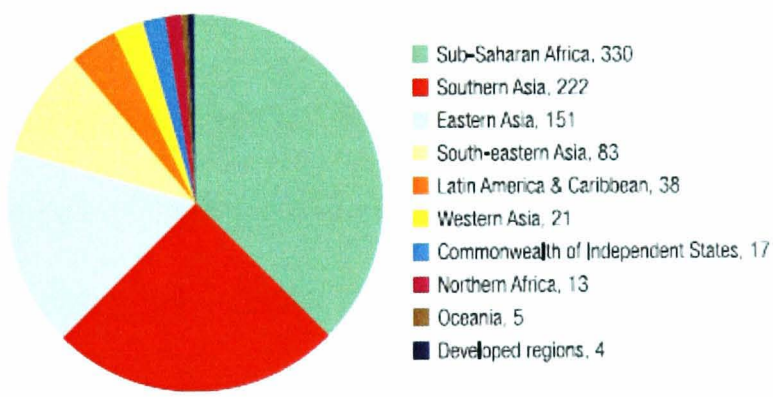


(image source: http://www.newint.org/features/2008/08/01/toilets-facts/)

1.2.2 WASH access and coverage

More than 850 million people in the world lack access to an improved water supply, and more than 2.5 billion lack access to improved sanitation facilities (WHO and UNICEF, 2010). The Millennium Development Goals (MDGs), established by the United Nations, aim to reduce by half the proportion of the global population without access to basic sanitation and safe drinking water supply (UN, 2000). Though the world is on track to reach the target for water overall, Sub-Saharan Africa has not realized the gains of the rest of the world (WHO and UNICEF, 2010). As shown in Figure 2-2 below, 330 million people in Africa remain without access to improved water supplies.

Figure 2-2: Proportion of global population without access to improved water supply in millions of people.

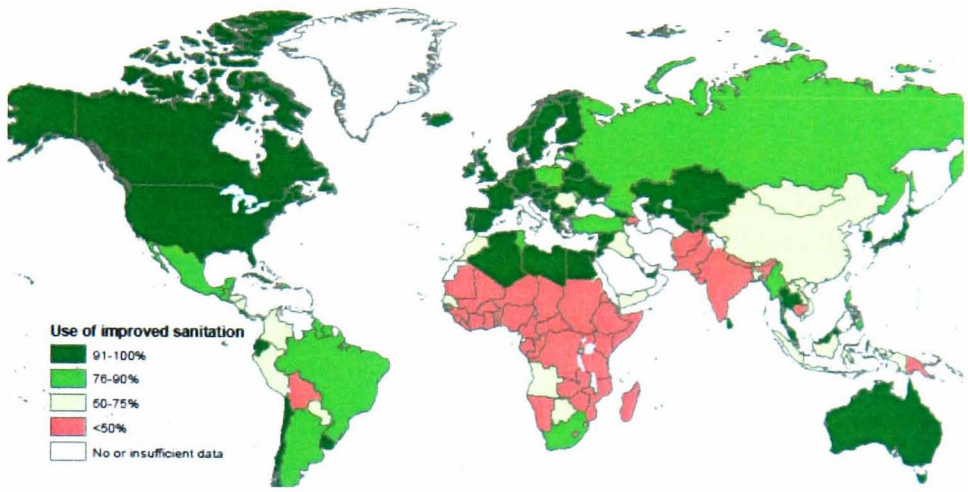


(Source: WHO, 2010)

Progress toward the sanitation target, however, lags seriously behind the MDG target, leaving billions unserved (WHO and UNICEF, 2010). Again, sub-Saharan Africa has the lowest rates for coverage of improved sanitation (Figure 2-3). The water and sanitation targets, embedded in MDG 7 on environmental sustainability, do not directly address the issues of health

(Rheingans et al., 2006). Even if these targets were met, those that remain unserved represent the majority of the burden of fecal-oral related disease (Blakely et al., 2005).

Figure 2-3: Percentage of the population without access to improved sanitation.



(Source: WHO, 2010)

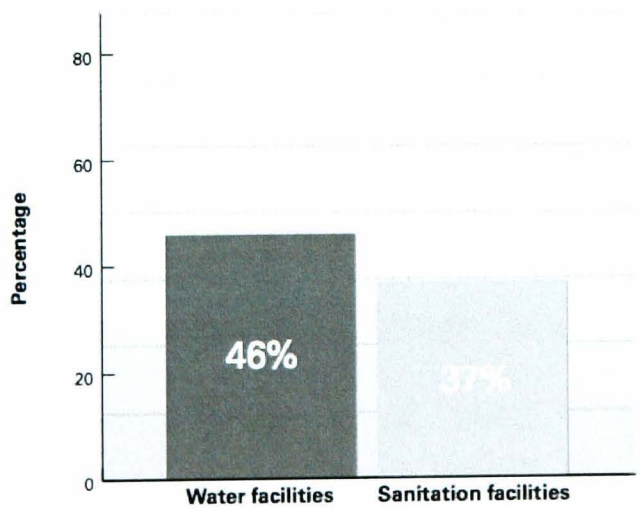
1.3 WASH in Schools

Schools are places for children to learn in both formal and informal ways. At school, children will congregate in social groups, practice learned behavior, develop and codify social norms, and try to conform (Sidibe, 2007). WASH access at school is a critical element of a healthy school environment: it can mitigate disease burden, impact students in ways beyond health, influence the community outside of the school, and reach vulnerable populations (Onyango-Ouma et al., 2005, Pearson and McPhedran, 2008, UNICEF, 2010). WASH improvements in turn may lead to improved school attendance and educational attainment, especially for girls (World Health Organisation, 2009b).

There is robust evidence of the health impact of household WASH conditions from community-based research (Esrey and Habicht, 1986, Fewtrell and Colford, 2004, Rabie and Curtis, 2006, Clasen et al., 2010, Clasen et al., 2007, Curtis and Cairncross, 2003). However, few studies have addressed the impact of school-level WASH conditions, despite increased interest in the WASH sector to focus on improving access in schools (UNICEF, 2010).

UNICEF estimates that in 2008, schools in their priority countries reported 46% with adequate water supply coverage and 37% with adequate sanitation coverage (UNICEF, 2009b). These data were taken from UNICEF reports in 33 countries for sanitation coverage and 25 countries for water coverage (Figure 2-4). Little additional data are available on WASH in schools coverage, let alone the health and educational impact of poor WASH in schools coverage.

Figure 2-4: Global WASH in schools coverage



Source: Extracted from 60 UNICEF country office annual reports, of which only 33 contained information about the proportion of primary schools with adequate water supply and 25 had data on sanitation facilities.

(Source: UNICEF (2010))

Access to school-based WASH is not explicitly enumerated in the United Nations Millennium Development Goals, which may explain the lack of funding and attention to the sector (United Nations, 2010). The Joint Monitoring Programme on Water and Sanitation (JMP), run by UNICEF and the World Health Organization (WHO), does not monitor school-level WASH provision. Neither does the United Nations Global Assessment of Sanitation and Drinking-water (GLAAS) Report estimate expenditures for water and sanitation programming for WASH in schools (World Health Organisation and UN Water, 2010, WHO and UNICEF, 2010).

Schools in low-income countries often include conditions that are not conducive to learning; and poor water, sanitation, and hygiene (WASH) conditions are contributors to this problem (Postlethwaite, 1998). In recent years, much attention has been dedicated to developing best practices for implementing, sustaining, and scaling school WASH programs (UNICEF and International Water and Sanitation Centre (IRC), 2005, Snel, 2004). Considerable anecdotal evidence exists on the impact of WASH in schools on health and educational outcomes, but few rigorous studies have been conducted. Key areas of focus have been the role of WASH in schools on reducing absence, diarrhea, and non-health related impacts of sanitation conditions (Bowen et al., 2007, O'Reilly et al., 2008, Blanton et al., 2010, Pearson and McPhedran, 2008, Miguel and Kremer, 2004).

1.4 Research questions

The goal of the research presented in this thesis is to inform policy on school-based WASH by addressing important gaps in the evidence on the impact of WASH in schools on absenteeism and health. The specific research questions are:

1. What is the impact of improved access to WASH in schools on pupil absence, STH reinfection, and diarrheal disease?
2. How do household WASH conditions modify the effect of a school WASH intervention on STH reinfection?

To this end I present four chapters (4-7) in the form of academic journal papers. These chapters address the role of our school-based WASH intervention in reducing absence (Chapter 4), reducing STH reinfection (Chapter 5), the modifying effects of household WASH access on STH reinfection (Chapter 6), and the effect of the intervention on diarrheal illness (Chapter 7). I have included a paper in the appendix that addresses household uptake of a point-of-use technology as a result of a school-based WASH intervention in India (Freeman and Clasen, 2010).

1.5 Project background

This research is embedded in a five-year applied research program entitled *Sustaining and Scaling School Water, Sanitation, and Hygiene plus Community Impact (SWASH+)*. The goal of this project is to explore the impact of school-based WASH programs on health and educational

attainment of children in Kenya. The project was funded by a $10.5 million grant by the Bill and Melinda Gates Foundation and the Global Water Challenge and is led by CARE International. Additional partners for SWASH+ include Water.org (formally WaterPartners International), the Millennium Water Alliance (MWA), and Emory University, an academic institution based in Atlanta, Georgia USA. Additional collaborators include the London School of Hygiene and Tropical Medicine (LSHTM), Kenya Great Lakes University of Kisumu (GLUK), University of Florida, Sustainable Aid in Africa International (SANA), and the Kenya Water and Health Organization (KWAHO). The Government of Kenya (GoK) Ministries of Water, Public Health and Sanitation, and Education are considered key stakeholders in this consortium.

SWASH+ has three primary objectives:

1. Identify, develop, and test innovative approaches to school- and community-based water, sanitation, and hygiene interventions that promote sustainability and scalability.
2. Provide and test an integrated safe water, sanitation, hygiene-promotion program in schools and communities that maximizes impact, equity, sustainability, and cost-effectiveness.
3. Develop and implement a scalable model for the delivery and financing of safe water, sanitation, and hygiene promotion to schools and communities based on lessons learned and innovative approaches that address the varying conditions found in schools and communities.

The first three years of SWASH+ included an applied research agenda based on a cluster-randomized trial of school-based WASH interventions in 185 public primary schools in Nyanza Province, Kenya. This applied research aims to document impacts of the project on the health and educational attainment of school children and the health of children under the age of five in associated communities.

SWASH+ was designed as an applied research project; the research was conducted in the context of assessing the effectiveness of WASH interventions implemented by CARE and its partners. Intervention components—including the technology hardware, behavior change components, and management—were "best practices" chosen by the implementing partners. The specific components had been refined over previous funding cycles by the implementing agencies. By design, researchers had minimal input into the implementation and were able to control only the study design, data collection, and analysis. The advantage of this type of research approach is that the implementation components had been refined and theoretically optimized to the target population. The costs associated with the implementation are comparable with other school-based WASH programs and are therefore considered potentially scalable.

At the same time, it is important to bear in mind that our findings reflect the way the intervention was actually implemented, not how they might be implemented elsewhere under other circumstances in a controlled experiment. As described more fully below, intervention components were sub-optimal,

either through failure of the school community to take up the intervention or due to failure of the implementing partners to effectively implement the project. As such, research findings should be considered evaluations of program "effectiveness" in a real world setting, rather than studies of "efficacy" in ideal conditions.

1.6 Roles and responsibilities

The research presented as part of this PhD thesis is embedded within the SWASH+ research project described above. The study designs were ultimately constrained by the overarching program objectives, logistical feasibility, and resource availability.

Except as expressly noted in this thesis, I was solely or principally responsible for all research described herein. I co-wrote the original research proposal for SWASH+, was the research manager in Kisumu, Kenya for the initial two years of the project and continue to serve as the Research Program Manager. My role in the SWASH+ project has been to develop field protocols and survey tools, manage data collection, oversee laboratory staff, manage and clean data, analyze data, and write up findings. I led the rapid assessment, school selection, and data collection for the first two years of the program and was the program manager for all data discussed in this thesis. As part of this work, I supervised three staff members from Emory University, seven staff members from Great Lakes University of Kisumu, and over 20 field data collectors and was the primary liaison between the research team and

implementing partners CARE International, Water.org, Sustainable Aid in Africa, and the Millennium Water Alliance.

Research projects are by nature collaborative, and many people have contributed to the research included in this thesis. Those collaborators who have contributed sufficiently to warrant authorship on individual chapters are included below, along with their contribution to the research output. In addition, as required by LSHTM, I have listed my roles for each paper at the start of each chapter.

Daniel Akoko: Laboratory technician, Great Lakes University of Kisumu; contribution to helminth detection methods, Kenyan research context, helminth expertise (Chapters 5).

Babette Brumback: Statistician, University of Florida; contribution to statistical analysis methods for analysis chapters (Chapters 4 and 5).

Simon Brooker: Reader, LSHTM; member of my PhD committee. Contribution to helminth research questions, context, and analysis methods for helminth chapter (Chapter 5)

Thomas Clasen: Senior Lecturer and PhD Adviser, LSHTM; Principal Investigator, Unilever WASH in schools assessment. Contribution to methods, research questions, research design and writing for all chapters.

Robert Dreibelbis: Research Manager, Emory Univeristy. Contribution to initial study design, absenteeism analysis, methods, and write-up for absentee chapter (Chapter 4).

Leslie Greene: Research Coordinator, Emory University. Contribution to absenteeism analysis, methods, and write-up for Chapter 4.

Richard Rheingans: Principal Investigator and PhD committee member, University of Florida. Contribution to overall project scope, research questions, study design, analysis, methods, and writing for all analysis chapters.

Shadi Saboori: Research Coordinator, Emory University. Contributor to field methods and data collection, writing for absence paper (Chapter 4).

2. Literature Review

2.1 Assessing impact: Health and non-health impacts of school WASH

There is a need to better understand the health and educational impact of access to WASH in schools. This review focuses on the three key WASH-related outcomes for school children most discussed in the literature: diarrhoea, soil-transmitted helminth infection, and absence from school. As mentioned in the previous chapter, diarrhoeal diseases cause considerable burden of the disease, consisting principally of mortality in children under five years of age (Kosek et al., 2003). As discussed more fully in this chapter, however, diarrhoea also is highly prevalent among school-aged children. Similarly, soil-transmitted helminth infection contributes to considerable disease burden among school-age children, and it is directly related to fecal exposure that can be mitigated by access to improved sanitation and hygiene behaviors. Absenteeism can serve as a proxy for health status, as sick children sometimes stay home from school. WASH conditions at school may also directly influence attendance by mitigating non-health related issues, such as privacy, menstrual hygiene management, and responsibilities of water collection for students.

In this chapter, I review the key reasons to address access to WASH in schools and explore the available research on three key impacts of WASH in schools. The results show that that there are few rigorous studies assessing the impact of WASH in schools on health and educational attainment. In this way, this chapter establishes the need for the research that was undertaken.

2.2 Justification an assessment of the impact of WASH in schools

Due to the considerable disease burden from diarrheal disease, research on the impact of WASH has primarily focused on how it has been shown to reduce diarrhea among children under five years through improved household impact (Fewtrell et al., 2005, Boschi-Pinto et al., 2008). However, this rationale ignores many other key impacts for WASH among older children where diarrhoeal morbidity is not as pressing of a health concern, since it will often not lead to mortality (with the possible exception of outbreaks of severely debilitating diarrhoeal illness such as cholera or among people living with HIV/AIDS). The discussion below briefly touches on the four key justifications for better understanding the role of improved WASH access at school.

1) Because they are places of congregation for children, schools are an important source of exposure to infectious diseases that present transmission dynamics that are different from those in the home.
2) Children may play a role as change agents in the home and as peer educators in the school, improving overall WASH-related behaviors.
3) There are considerable non-health related outcomes embedded in improved school WASH conditions that are not well understood or quantified.
4) Improving school WASH is an opportunity to improve equitable access among populations traditionally missed by other service delivery improvements at the community-level.

2.2.1 Disease transmission at school

For school-age children, addressing WASH conditions at home may be necessary but not sufficient to ensure that they can access water and sanitation throughout their day. The lack of access to safe water, improved sanitation, and hygiene facilities at school likely increases risk of infection, regardless of access at home. Lack of access at school may lead to increased transmission within the community.

Studies focused on reducing environmental risk factors of WASH-related disease have predominantly focused on household-level effects (Cairncross et al., 2010, Esrey et al., 1991). An exception in the literature is a selection of publications from a community-level sewage improvement study in Salvadore, Brazil (Moraes and Cairncross, 2004). Barreto (2010) suggests that the significant reductions in helminth infection are a result of reducing exposure at the community (public) domain. Similar analysis of the program's impact on diarrhoeal disease revealed no modifying effect of household sanitation on the effect of community sewerage in reducing disease burden (Barreto et al., 2007). The researchers also evaluated the attributable fraction of household and community WASH effects responsible for reductions in helminth infection and found the community-level effects to be more significant (Mascarini-Serra et al., 2010). While these studies were not conducted in schools, they are illustrative of the potential for public-domain WASH improvements to reduce disease burden and routes of disease transmission.

With regards to disease transmission, one typology that has been suggested is the concept of domestic and public transmission routes (Cairncross et al., 1996). Using that conceptual model, as discussed above, we understand that the domestic transmission route has been heavily studied and few studies regarding the role of WASH have been done to understand the public domain. Schools are a public domain of importance, given the role of schools as nodes of pathogen transmission and the social networks of children as harbingers of the spread between domestic domains (Cauchemez et al., 2011). Some researchers, such as Eisenberg and colleagues (2007) have attempted to model the transmission between public and domestic domains, reporting that background infection rate plays a considerable role in what transmission route is most critical. In that context, a better understanding of the role of schools as nodes of WASH-related illness among school children and the community at large is warranted.

2.2.2 Non-health related impacts

School WASH may influence pupil well-being and attainment potential in ways beyond pathogen control (Pearson and McPhedran, 2008). In schools without adequate water supply, the burden of collecting water often falls on the students, who report this chore, compared to others, as both the most demanding in time and energy and as the most dangerous (Hemson, 2007). Fetching and carrying water often causes children to miss school or arrive late, especially among students who must make more than one trip to collect water per day (Hemson, 2007, Fisher, 2004). Fetching water also detracts

from children's time to study, and decreases their morale and alertness in class (Hemson, 2007). Teachers may also miss school due to the necessity of carrying water, which may impair the educational attainment and attendance of pupils. It is difficult to attract and retain teachers in schools that do not have adequate WASH facilities (Fisher, 2004, Pearson and McPhedran, 2008). Improvements of school WASH may affect non-health outcomes, such as attendance, behaviors and attitudes of pupils, school pride, privacy and access to facilities, and stress. These changes, along with the health gains, may positively impact test scores, cognition, and grade progression.

Of these non-health related outcomes, school absence may prove to be a useful indicator of health outcomes as well as an intermediate outcome indicating long-term educational gains. Two studies that assessed the impact of school-level WASH improvements on absence analyzed the results only at the cluster-level (school), and thus were not able to ascertain the contribution of school and household-level effects (Blanton et al., 2010, O'Reilly et al., 2008). A review of the literature revealed no studies that assessed the impact of both household and school-level WASH access on health.

2.2.3 Children as change agents

Children can serve as agents of change within the school as peer educators and within the broader community (Alibhai and Ahmad, 2001, Sidibe, 2007). With the advent of free primary education and the dramatic increase in school enrollment over the last decade, providing schools with improved WASH

access represents an opportunity to target children who may not have access at their home (United Nations, 2010). Studies in Kenya have shown that increased education of WASH behaviors at school can lead to improved practices at home (Blanton et al., 2010, O'Reilly et al., 2008). In these studies, a simple hygiene promotion message and provision of water treatment products at school increased adoption at home by 6-8 percentage points; these gains were sustained one year following the intervention (Blanton et al., 2010). Similarly, data from work in Kenya revealed that promotion of water treatment practices in school increased purchase and use of water treatment products in the home (Rheingans et al., 2009). Findings that children can act as change agents in the home in sub-Saharan Africa is most surprising, since culturally, knowledge is often associated with old age (Mwanga et al., 2007).

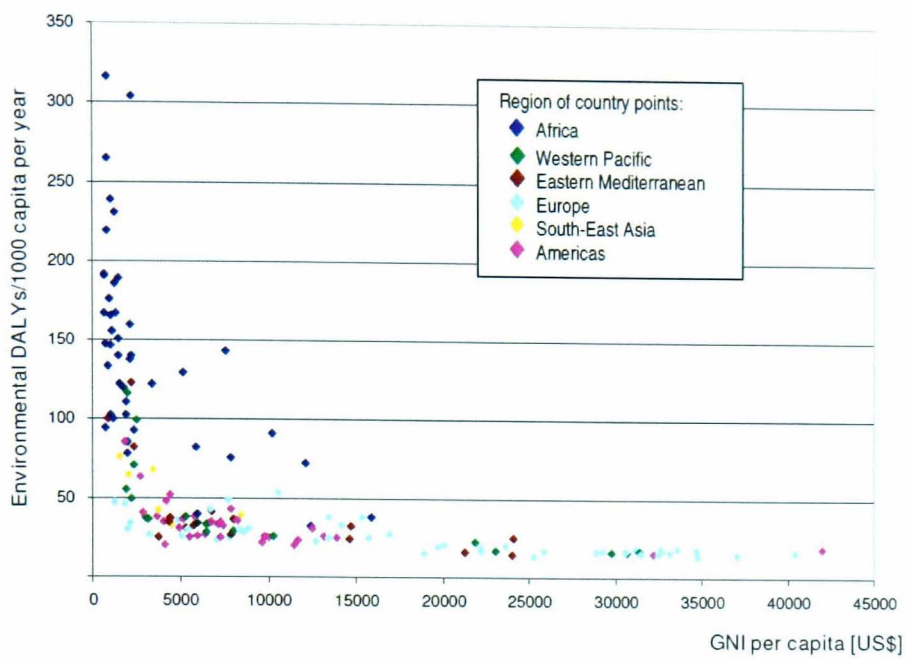
While children can contribute to health messages in the home, they must be engaged in a structured way; projects that fail to do so may not result in significant changes in practice at home (Onyango-Ouma et al., 2005, Freeman and Clasen, 2010). Children have their own social rules and priorities that must be engaged and accommodated to ensure that WASH promotion at school is effective (Sidibe, 2007). Similarly, WASH messages are most effective when they engage with local contexts and cultural perceptions (Aldinger et al., 2008). While the issue of children as change agents is not specifically addressed in the thesis chapters, I have addressed the issue in a previously published paper included in the appendix (Freeman and Clasen, 2010).

2.2.4 Equity

As discussed in the previous chapter, much of the attention on improved WASH access is focused on the MDGs for water and sanitation. However, even if the MDGs are met, a substantial number of people will remain without access to safe water and improved sanitation, especially the rural poor (WHO and UNICEF, 2010). In general, water and sanitation infrastructure has reached the low hanging fruit, those with proximal subsurface water and those in emerging middle-income countries such as India and China (World Health Organisation and UN Water, 2010). Low income countries received only 42% of funding for infrastructure improvement, and most systems are targeted at large systems designed for urban infrastructure improvement (World Health Organisation and UN Water, 2010).

Those who live in impoverished areas are the same populations at greatest risk of disease. As shown in Figure 2-1, poorer countries have substantially greater number of disability-adjusted life years associated with poor environmental conditions. In Kenya alone, poor access to WASH is estimated to cause approximately 23,600 deaths per year (World Health Organization, 2007). In these settings, improving environmental conditions – specifically, improved WASH access and indoor air pollution – could reduce between 13% and 37% of global deaths (Pruss-Ustun et al., 2008).

Figure 2-1: Number of disability adjusted life years (DALYs) compared to wealth.



(Source: Pruss-Ustan (2008))

Gender equity is also a critical component of school outcomes that could be mitigated with WASH improvements (Nahar and Ahmed, 2006). Girls often lag behind boys in terms of school enrollment, and differences in attainment between the genders may play a significant role in myriad development outcomes (Oster and Thornton, 2011, Behrman and Rosenzweig, 2002). The dramatic rise in school enrollment through free primary education has led to fewer non-enrolled students and more marginalized pupils attending school (World Bank, 2011). However, the lack of sanitation and hygiene infrastructure at school and poor access to water at school may limit attendance by girls (Sommer, 2009, Sommer, 2010).

Opportunities to work within the educational sector, engage children as change makers in the home, address public domains of disease transmission, and address both health and non-health impacts of WASH make schools a compelling place for improving WASH access. The lack of research exploring

the impact of school-based WASH on health and non-health impacts deserves attention and raises questions that warrant additional investigation. While not explicitly part of this thesis, a paper addressing the role of WASH is currently under development for journal submission (of which I am a co-author) that addresses issues of equitable benefit to school WASH improvements (Dreibelbis et al., 2011).

2.3 Diarrhoea

2.3.1 WASH and diarrhoea

Diarrhoeal diseases are a leading cause of morbidity and mortality, resulting in over two million deaths per year globally (Pruss et al., 2002, Kosek et al., 2003, Boschi-Pinto et al., 2008). Since the publication of the seminal book *Drawers of Water* in 1972, there has been increased attention on poor WASH access and diseases such as diarrhoea (White et al., 1972). In the first systematic review of the impact of WASH on diarrhoeal disease, Esrey and colleagues drew results from 67 studies in 20 countries and estimated that the median reduction in diarrhoeal morbidity rates resulting from WASH interventions was 22-27% (Esrey et al., 1985). Similar results were shown in a follow-up review, where the median reduction for diarrhoeal disease morbidity was found to be 22-26% (Esrey et al., 1991).

Subsequent reviews expanded—and in some cases challenged—Esrey's conclusions (Esrey and Habicht, 1986, Fewtrell et al., 2005, Curtis and Cairncross, 2003, Clasen et al., 2007, Clasen et al., 2010). Curtis (2003)

showed much higher effectiveness for hygiene interventions, while Fewtrell (2005) showed that water quantity / access improvements were not statistically effective against diarrhoea. Improved sanitation was found to play a more important role in enhancing child health than improved water supply (Esrey and Habicht, 1986). One of the main challenges pointed out by a later review was that water quality in most of these studies was assessed at the source, not at the point of use (Fewtrell et al., 2005). It is now known that significant contamination occurs between community water sources and the home due to poor transportation and storage practices, which provide opportunities for water that was clean at its source to become contaminated with pathogens (Roberts et al., 2001, Wright et al., 2004, Levy et al., 2008). However, recent reviews have shown that point-of-use interventions are more effective than source-based interventions to improve water quality and health (Waddington et al., 2009, Fewtrell et al., 2005, Clasen et al., 2007).

As part of a Cochrane meta-analysis, Clasen and colleagues summarized evidence of the impact of improved excreta disposal facilities (improved sanitation) on prevention of disease and infection (Clasen et al., 2010). The 13 studies that met the eligibility criteria demonstrated a relationship between sanitation improvements and reduced disease morbidity, including reductions in helminth infections. Though the review was unable to report a pooled estimate of effect, the studies included in the review were generally consistent with the reduction in risk of diarrhoea reported by Esrey (1985) and Fewtrell (2005). However, heterogeneity exists among the findings in the available literature, and 12 of the 13 intervention studies concurrently assessed water

supply and/or hygiene improvement with sanitation, preventing unqualified endorsement of sanitation facilities alone. A summary of these findings are found in Table 2-1.

Table 2-1: Findings from meta-analyses on WASH interventions to reduce diarrhoeal disease

Intervention (improvement)	Esrey *et al* (1985)	Esrey *et al* (1991)	Fewtrell *et al* (2005) (95% CI)	Clasen *et al* (2007) (95% CI)	Clasen *et al* (2010) (95% CI)	Waddington (2009) (95% CI)
Water Quantity	25% (0-100%) (17)	27% (7)				0.98 (0.89-1.06)
Water Quality			0.69 (0.53-0.89) (15)	0.57 (0.46-0.70) (38)		0.58 (0.50-0.67)
Water quality and availability	37% (0-82%) (8)	16% (22)	0.75 (0.62-0.91) (6)			
Water and sanitation		20% (7)				
Sanitation	22% (0-48%) (10)	22% (11)	0.68 (0.53-0.87) (2)		0.67 (0.50-0.82)	0.63 (0.43-0.93)
Hygiene		33% (6)	0.63 (0.52-0.77) (11)			0.69 (0.61-0.77)

For studies by Esrey, estimates of effect is the median reduction in diarrhoeal disease from the reported studies; for other studies, estimate of effect is the pooled rik ratio from meta-analysis using random effects model. To compare results, the precentage reduction is 1-RR (eg. RR of 0.69 implies a 31% reduction in risk). *Source: adapted from Clasen (2009)*

2.3.2 Effect from school-based WASH improvements

Few of the studies reviewed above reported diarrhoea in school-age children (5-18 years of age) and none included primary school populations. As with nearly every rigorous study of point-of-use water treatment, interventions to improve water quality were randomized at the household-level or among clusters of households (Clasen et al., 2007). Only one study - by Wei (1998) and colleagues - was identified as part of recent reviews by Clasen (2010), Waddington (2009), and Hunter (2009) to address the effect of school-based interventions on reduction of diarrhoeal diseases. Wei found that a comprehensive schools-based WASH intervention reduced diarrhoea among primary and secondary school children by 80% (Wei et al., 1998).

Interventions that promote washing hands with soap have been associated with a 47% decrease in the risk of diarrhoeal disease and a 48-59% reduced risk of more severe illness in communities (Curtis and Cairncross, 2003b).

Hand hygiene education programs also have the potential to be cost-effective in the primary school setting. One trial in a United States classroom that provided hand-sanitizer and hygiene education demonstrated the capacity to save the school $24,300 each year by limiting extra illness-related work for teachers (Guinan et al., 2002).

One school-based study that assessed the impact of school WASH on diarrhoea was available in the peer-reviewed literature. Migele and colleagues (2007) measured the impact of a school water treatment and hand washing project on the incidence of clinic visits at school for diarrhoea in one private boarding school in Kenya. Researchers reported a 36% drop in local clinic visits for diarrhoea-related symptoms following implementation of the intervention, as compared to the previous year. However, no statistical tests of association were presented and the sample size was one school. There were a number of challenges with the research design, including the small sample size and the lack of a control group. Because of this, the ability to attribute the impact to the intervention cannot be properly established.

2.4 Intestinal nematodes (soil-transmitted helminths)

The three most common soil-transmitted helminthes (STHs)— *Ascaris lumbricoides* (roundworm), *Trichuris trichiura* (whipworm); and *Ancylostoma duodenale* and *Necator americanus* (hookworm)—cause chronic infections in the intestinal tract (WHO, 1995, Bethony et al., 2006). The ova are shed in the feces of infected children and adults. Transmission occurs through physical contact (hookworm) or ingestion of soil or food (*Ascaris* and

Trichuris) that has been contaminated with helminth ova (Stephenson et al., 2000a, Brooker et al., 2004, Crompton, 2001). Chronic helminth infection with large numbers of worms causes malnutrition due to loss of appetite and malabsorption of nutrients. Children with helminth infections may be stunted or underweight, and may suffer from bowel obstruction (*A. lumbricoides*) or anemia (hookworm and *T. trichiura*). Evidence suggests that intense infections may adversely affect cognitive development in schoolchildren and that even light worm burdens may have a marked impact on the health of younger children (Brooker and Bundy, 2008). Other symptoms of helminth infection include abdominal pain, listlessness, fever, vomiting, diarrhoea, and general malaise (WHO, 1995).

Recent studies have measured the prevalence of helminth infections among schoolchildren (ages 5-15) in East Africa. Estimates of the prevalence of infection range from 14-79% for *Ascaris,* 22-98% for *Trichuris*, and 36-96% for hookworm. (Miguel and Kremer, 2004, Albonico et al., 1999, Stephenson et al., 1990, Stephenson et al., 1989, Stephenson et al., 1993b, Thiong'o et al., 2001). The wide variance in infection rate has much to do with climatic condition, seasonality, soil type, and poverty (Brooker and Clements, 2008, Hotez et al., 2006). There is ongoing effort to understand and map the spatial patterns and distribution of worm infections globally as part of the Global Atlas of Helminth Infection (Brooker et al., 2009). Broad-based deworming has become recognized as a cost-effective, mainstream approach to STH control, either through communities or schools (World Bank and WHO, 2003, Massa et al., 2009).

2.4.1 Impact of reduced helminth infections

Strong evidence links reduced helminth infection to improved health (Dickson et al., 2000). Studies of the use of albendazole to treat helminth infections have shown improved physical fitness and appetite, improved growth, weight gain, reduced diarrhoea, and decreased anemia among students treated compared to those not treated (Stephenson et al., 1993a, Adams et al., 1994, Albonico et al., 1998, Stoltzfus et al., 1998, Sur et al., 2005, Stephenson et al., 2000b, Stephenson et al., 2000a, Stephenson, 1994, Brooker, 2010). Children with poor baseline health – specifically, those with stunting and anemia - often benefitted the most from deworming campaigns (Beasley et al., 1999, Simeon et al., 1995). Early childhood health problems resulting from STH infection – malnutrition, anemia, stunting – have been projected to lead to lower long-term productivity in adulthood, due to decreased years of schooling (Guyatt, 2000).

The link between helminth infections and cognitive function is not yet clear (Nokes and Bundy, 1994, Dickson et al., 2000). Studies have found a link between reduced worm burden and improved cognitive test scores (Nokes et al., 1992), and associations have been found between worm infection and decreased recall ability (Sakti et al., 1999). Other studies have found that age might either decrease or increase the interaction of infection and reduced cognitive function, results that may be dependent on the type of infecting worm (schistosomes and hookworm, respectively) (Nokes et al., 1999, Sakti et al., 1999).

The impact of reduced helminth infection on school performance, enrollment, and attendance has also not been definitively established (Watkins et al., 1996, Raj et al., 1997). There are some indications that decreased helminth infection status is linked to increased school enrollment (Montresor et al., 2001, Gyorkos et al., 1996, Fentiman et al., 2001), though at least one study has offered discordant results (Olsen, 2003). Additionally, a study in Kenya reported a 25% decrease in school absenteeism following deworming (Miguel and Kremer, 2004). Six months following treatment with albendazole, students aged 6 to 12 years in Jamaica did not show significant improvements in either physical growth or academic test scores when compared to controls (Simeon et al., 1995). Stunted children have shown improved attendance following treatment with albendazole (Simeon et al., 1995), which indicates that school WASH may benefit those students most at risk for reinfection, since these are often the same children without access to proper facilities at home.

2.4.2 Chemotherapy

Due to the high prevalence of infection and the serious health impacts of helminth infections on schoolchildren, the WHO recommends school-based antihelmethic treatments be given every six months (400 mg dose of Albendazole) (WHO, 1999). An estimated 70% of global infections could be mitigated by treating schoolchildren (Chan, 1997). Chemotherapy is a cost-effective way to reduce helminth infection (Bundy and Guyatt, 1996). Treatment with albendazole has been shown to have an cure rate of 94% for *Ascaris*, 44% for *Trichuris*, and 78% for Hookworm (Keiser and Utzinger,

2008). These numbers refer to the cure rate of albendazole, meaning the percentage of individuals who became helminth negative after treatment. The authors were unable to calculate the reductions in worm burden However, reduction in worm burden among individuals is density dependent, meaning that those with higher levels of worm burden are less likely to become worm-free following chemotherapy. In the absence of control measures aimed at reducing exposure, successful treatment of STH infections is followed by re-infection as quickly as 4 months, necessitating periodic treatments (Albonico et al., 1995, Quinnell et al., 1993).

In one study in Tanzania, the authors found that there was clustering of STH infections in households where school-age children were infected (Killewo et al., 1991). This finding points to children as the likely index cases for household outbreaks of disease. As such, it is likely that school-age children are the transmitters of helminth infections to households.

Deworming children also has been shown to improve non-health outcomes such as diarrhoea (Miguel and Kremer, 2004). In a follow-up study of these children over ten years following enrollment in the trial, children enrolled in the intervention arm of the study had higher wages than those in the control (Baird et al., 2011).

2.4.3 Risk factors of STH infection

Due to rapid reinfection with helminths following deworming, improvements to WASH infrastructure and behaviors are of critical importance to achieve both

long-term reduction in both the prevalence and severity of infections (Asaolu and Ofoezie, 2003). Indeed, promotion of sanitation provision and shoe wearing was the strategy employed by the Rockefeller Sanitary Committee to eradicate hookworm in the American south in the early part of the 20th century (Page, 1912).

Esrey and colleagues (1991) synthesized findings from 144 available articles comparing WASH access and A*scaris* and hookworm infection. Following a combination of improved water supply, improved sanitation, and provision of chemotherapy, median reduction in morbidity for A*scaris* infection among the four rigorous studies was estimated at 29% (Arfaa et al., 1977, Henry, 1988, Sahba and Arfaa, 1967, Schliessmann et al., 1958). Only one rigorous study was reportedly available to measure the reductions in hookworm infection attributable to WASH interventions (Arfaa et al., 1977). The impact of WASH improvements on STH disease severity was more pronounced than its effect on STH prevalence or incidence (Esrey et al., 1991). While Esrey found that the impact of WASH provision in conjunction with chemotherapy was greater than the impact with WASH alone, the analysis did not consider the additive effect of WASH on worm burden over time. Implications for this in the design of our study is discussed in Chapter 3, section 4.4.

A number of more recent cross-sectional studies have revealed associations between sanitation and hygiene access and STH infection. In Sri Lanka, though Gunawardena and colleagues (2004) recommended improved sanitation and hygiene education to reduce STH infection, drinking of unboiled

water was the only household risk factor found associated with *Ascaris* infection. Reported handwashing after meals was associated with reduced intensity of worm infection, but the p-value was marginally significant (p=0.07). Hookworm prevalence was associated with water source and latrine access, though absence of a latrine in the home did not increase the intensity of infection (Gunawardena et al., 2005). The study was performed on populations age 2 – 74, where peak infections were found during higher temperature months.

In Assam, India, researchers found a number of risk factors for STH polyparasitism that included socio-economic status, age, household crowding, education level, use of footwear, religion, defecation practices, and water source type (Traub et al., 2004). The authors' recommendation was for the use of broad-spectrum anthelminthics in concert with sanitation improvements.

Risk factors for *ascariasis* in Nigeria among school age children were identified as socio-economic status, access to sanitation and water supply, parents' educational background, number of biological parents living with the child, and the number of playmates (Ugbomoiko et al., 2009). Latrine access was the most critical risk factor. However, the authors noted that an integrated approach – notably behavior change education – may be critical, since improved WASH access will not have an effect if the latrines are not used correctly. There may be a threshold of investment below which even

investment in sanitation and water supply improvement may not improve STH morbidity in the absence of health education (Asaolu et al., 2002).

In one study with particular relevance, distance from the Lake Victoria is a significant risk factor for STH infection, suggesting why schools located in lakeside villages had lower baseline infection (Olsen et al., 2001). Additional risk factors for STH infection in Kisumu, Kenya included latrine access, handwashing with soap, and household crowding. Geophagy (earth eating), a type of pica, also plays a significant factor in STH infection levels in Western Kenya (Luoba et al., 2005). An anthropological approach revealed that worms were not considered a serious problem; however, since soap and latrines were in demand in the study area, the authors identified promotion of these products and behaviors as a feasible way to reduce STH morbidity (Olsen et al., 2001).

Key predictors of STH infection among school-age children in Cuba included lower parental education, absence of toilet, and drinking water source (Wordemann et al., 2006). Latrine conditions, as well as shoe-wearing and having another household member infected with STH, were found to be significant determinants of infection of pre-school children (Stothard et al., 2008). Use of manure for fertilizer was highly correlated with Hookworm infection, though it did not affect the prevalence of Ascaris or Trichuris infection (Yajima et al., 2009). Extensive household latrine coverage is not sufficient to reduce STH infection in areas where use of manure for fertilizer is prevalent (Yajima et al., 2009). The use of human manure for agriculture, as

well as exposure to inadequately treated latrines, has been identified as a risk factor elsewhere (Corrales et al., 2006).

One randomized study in Palestine assessed the impact of hygiene education on prevention of STH reinfection (Kanoa et al., 2006). Schoolchildren receiving health education for 6 months following deworming showed a statistically significant difference in reinfection rates as compared to those that received deworming only (82.9% reduction compared to 71.2%). Results of this study are questionable, since the primary sampling unit of this study was the school, and it was unclear whether school clustering had been accounted for in the analysis.

Though many studies have identified the association between WASH access and STH infection, nearly all have used quasi-experimental designs. While school children are a population at risk of STH morbidity, none have used a cluster-randomized design to assess the impact of school-level WASH improvements on reducing STH infection in conjunction with chemotherapy. Additionally, none have attempted to quantify the contribution of household and school-level WASH access and behaviors on STH reinfection.

2.5 Absenteeism

2.5.1 Impact of school attendance

Though enrollment rates in sub-Saharan Africa have risen considerably in the past decade, the region still accounts for nearly 50% of children not enrolled in primary school (United Nations, 2010). In Kenya, 83% of eligible children

were enrolled in primary school in 2009 (World Bank, 2011). Even among those enrolled, consistent attendance at school is often a challenge; studies in Nyanza Province, western Kenya have revealed absentee rates of between 8 and 10 percent (Blanton et al., 2010).

Evidence suggests that increasing school attendance can improve educational achievement. Through a quasi-experimental study conducted in Philadelphia, PA, Gottfried and colleagues (2010) found that days of school attendance was positively correlated with educational metrics such as grade point average, and standardized reading and math scores. A longitudinal study by Carroll and colleagues (2011) revealed similar results: that the more frequently children between 7 and 11 years old are absent, the lower their reading and math comprehension as compared to their age mates. No studies were found that evaluated this issue among low-income settings.

In addition to the importance of school attendance on educational outcomes, school absenteeism has been shown to serve as a proxy for health status among children in developed countries (Houghton, 2003). In developing country settings, absenteeism has been shown to be associated with public-domain environmental exposures such as air pollution and asthma (Gilliland et al., 2001, Moonie et al., 2008, Park et al., 2002, Chen et al., 2000). In one study, Branham (2004) and colleagues found that school infrastructure, including poor janitorial services, negatively impacted school attendance.

2.5.2 Absenteeism and WASH

As with the impacts of school attendance on educational outcomes, most of the available studies linking school-level WASH to absenteeism due to poor health have been conducted in high-income settings, such as the United States. These studies focused on establishing a link between absenteeism and handwashing with hand sanitizers (either alcoholic or non-alcoholic) (Dyer, 2001, Hammond et al., 2000, White et al., 2001, Guinan et al., 2002, Morton and Schultz, 2004, Sandora et al., 2008). Results revealed a 20-51% reduction in absenteeism between the intervention and control groups; however, as corroborated by a systematic review conducted by Meadows and Le Saux (2004), available studies were found to be of low quality. There were no calculations of sample size, explanations for drop-outs, or accounting for clustering. With the exception of Hammond (2000), all studies relied on data from selected classrooms in five schools or fewer.

A study by Bowen and colleagues (2007) did evaluate the impact of different levels of hygiene improvement on absenteeism in Chinese primary schools. Students in an expanded hygiene education program – which included education, soap provision, and enlistment of student hand washing "champions" – reported 42% fewer absence episodes and lower median duration of absences, as compared to the control group. Schools that received only education in the schools tended towards reduced absence among students, but results were not significant.

In our previous study in Western Kenya, absenteeism was measured in nine schools that had received a water treatment and hygiene program the previous year (O'Reilly, Freeman 2008). In the nine intervention schools, absenteeism was reduced by 35%, while it increased by 5% in nine nearby control schools over the same time period. There are a number of limitations to this study, namely that the schools were not randomized as control and intervention *a priori*, and there could be a Hawthorne effect in the teacher-reported absenteeism. However, this is the only study to assess the role of school-based water treatment and hygiene education on absenteeism in schools in low-income settings.

Absenteeism might serve as proxy not only for health, but also for other factors related to WASH. The burden of collecting water may lead to pupil absence (Hemson, 2007, Fisher, 2004). Among girls, there are myriad factors associated with sanitation, hygiene, menstrual management, privacy, and safety associated with school WASH conditions that may influence pupil attendance (Pearson and McPhedran, 2008).

Haller and colleagues (2007) estimate that achieving the water MDGs will avert 76 million lost days at school (using an estimate of three days of absence per incidence of diarrhoea); with the achievement of the sanitation and water MDGs, they estimate 254 million days of absence averted. Yet these numbers are estimated using only diarrhoeal disease and not accounting for other health issues related to WASH, such as malaria, helminth infection, and respiratory infection (Rabie and Curtis, 2006). Additionally,

these numbers are based on household-based access, not school access, again highlighting the lack of available information on the impact of school WASH access.

No studies have used a cluster-randomized design to assess the impact of a comprehensive WASH in schools on reduced absence of primary school pupils.

3. Methods

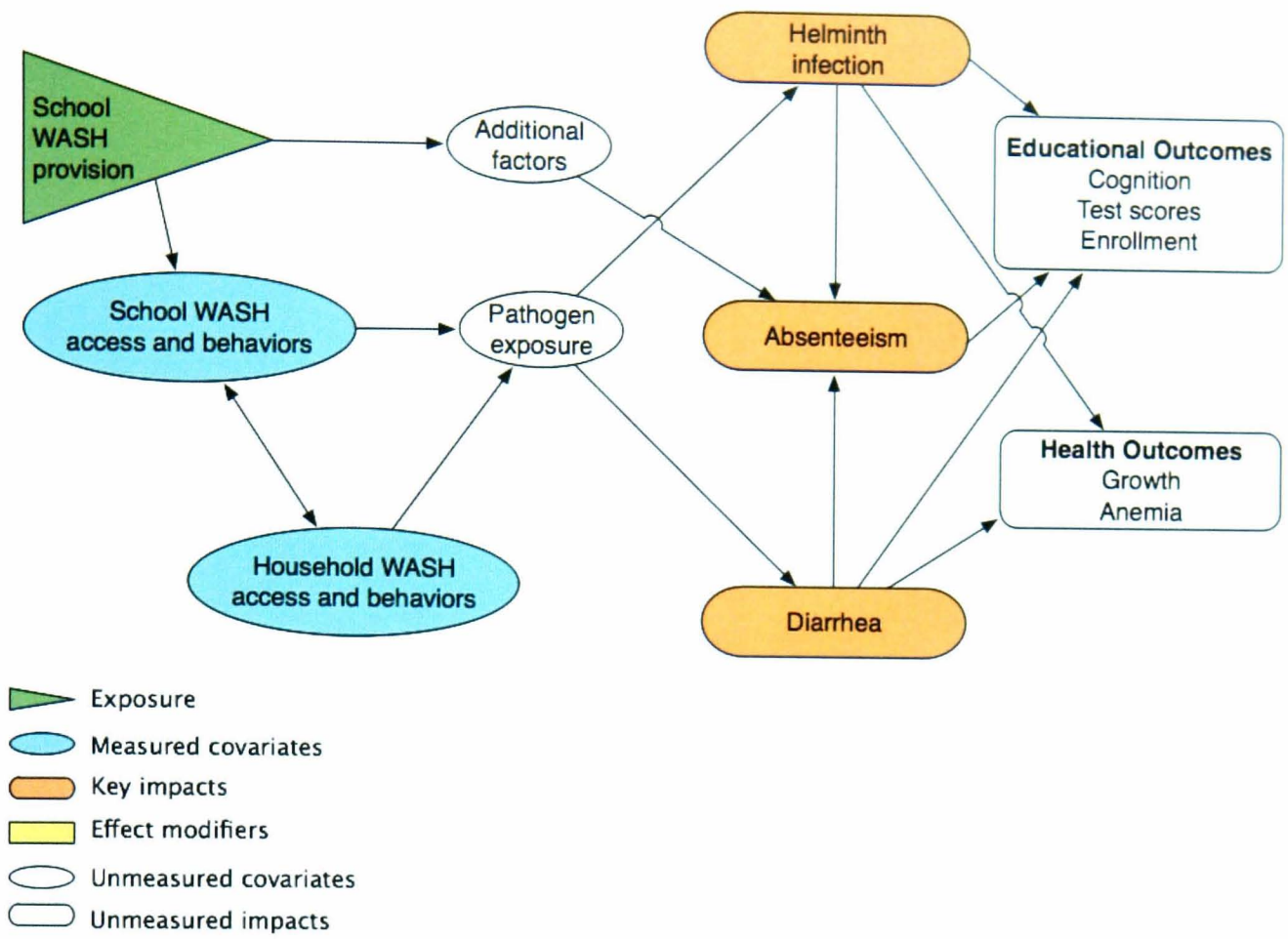
3.1 Research Questions

The overall goal of this research is to quantify the impact of improved access to WASH in schools on the health and educational attainment of primary school children. This dissertation focuses on two key research questions:

1. What is the impact of improved access to WASH in schools on pupil absence, STH reinfection, and diarrheal disease?
2. How do household WASH conditions modify the effect of a school WASH intervention on STH reinfection?

As discussed in the previous literature review chapter, our three key outcomes of interest are diarrhoea, STH infection, and absence. We hypothesize that improvement to school-based WASH infrastructure and hygiene education will result in reduced burden of disease and greater pupil attendance at school. The conceptual framework for this hypothesis is shown in the conceptual framework below (Figure 3-1).

Figure 3-1: Conceptual framework



The exposure of interest is the random allocation of school-based WASH improvements in hygiene behaviors and WASH infrastructure. Our measured covariates include school and household self-reported and observed WASH behaviors of pupils and maternal household heads. Our key outcomes are STH infection, absenteeism, and diarrhoea. These outcomes in turn influence downstream impacts such as growth, cognition, and long term economic benefits that have been discussed in the literature, but are unmeasured in our study design.

Whether improving school WASH access offers the potential to impact the outcomes of interest depends, like all environmental health interventions, on

its ability to meaningfully impact on adverse exposure. Pathogen exposure for school children may be mitigated by the intervention in a number of ways, including:

- Supply of drinking water with reduced levels of fecal contamination. This contamination could be source-based contamination, or from pathogens introduced during water handling during transportation or water storage. The program provided water treatment technology, as well as water storage containers with tap, lid and narrow mouth to reduce pathogen contamination/recontamination.
- Increased water quantity, which enables increased amount of water for drinking, personal hygiene, hand hygiene, and cleaning. Any of these activities might serve to reduce pathogen exposure. Schools in the water-"scarce" group received water supply improvements, while schools in water-"available" group received handwashing and drinking water containers to assist schools in water provision to large numbers of enrolled pupils.
- Separation of human waste in improved latrines. Provision of additional latrines at the school reduces the number of pupils that defecate openly. By separating human waste, use of latrines reduces individual reinfection, as well as reducing infection between individuals.
- Reduced hand contamination through handwashing with soap. Improved handwashing behaviors, specifically at key times such as before eating and after defecation, will reduce exposure to fecal pathogens and reduce overall burden of disease.

The reduction in pathogen exposure may prevent individual reinfection and also reduce overall disease burden at the school or community level.

However, besides pathogen exposure, there are additional factors that may improve school attendance indirectly. These factors are largely unexplored in the literature, but may include reduction in child-care responsibilities (if the program reduces overall burden of disease in the community) or increased access to water leading to reduced water collection duties at the household level. Increased access to sanitation and personal hygiene facilities at school may improve attendance during illness if pupils feel more comfortable using the facilities and may improve attendance for girls during menstruation.

There are key measured covariates that we explore not only to quantify the impact of the intervention, but also to assess why and how school WASH improves health and attendance. Some of these measured covariates include the school WASH improvements themselves, since this program is an effectiveness trial of a real-world development program. Unlike a drug trial, allocation of WASH improvements will not be uniform throughout all intervention schools. Schools start with varying measures of school access, and individual projects at school will vary in terms of success. Other measured covariates include household WASH access. A key question in this research is to better understand how the household-level WASH access mitigates the impact of improvements to school WASH access.

Of course, there are other unmeasured confounding variables that may mitigate program impacts. These variables may include head teacher

leadership, teacher engagement in the program, community reception to the program, community-level disease prevalence, cultural factors, and government policy. A critical unmeasured covariate is the impact of the violence that ensued following the Kenya presidential election in January 2008, which caused significant violence and migration in Western Kenya and forced the shutdown of the program for four months.

3.2 SWASH+

3.2.1 Research Setting

The research for this thesis is embedded in the applied research project *Sustaining and Scaling School Water, Sanitation, and Hygiene plus Community Impact* (SWASH+). This section describes the project initiation, site selection, and components of the implementation of SWASH+ that are not covered in individual chapters. Details on the individual field and analytical methods are covered in the individual chapters of the thesis.

3.2.2 Goals and research questions

As discussed in chapter 1, the research described in this thesis is embedded in a five-year applied research program entitled *Sustaining and Scaling School Water, Sanitation, and Hygiene plus Community Impact (SWASH+).* The goal of SWASH+ is to quantify and qualify the impact of a school-based WASH program on health and educational attainment of children in Kenya and to use data to advocate with the Kenyan Government for policy changes on the national level. The program is funded by a grant from the Bill &

Melinda Gates Foundation. The lead implementing agency is CARE – International, based in Atlanta, Georgia. Other implementing agencies include Water.org, Kenya Water and Health Organization, Sustainable Aid in Africa, and the Millennium Water Alliance. The lead research institution is the Center for Global Safe Water at Emory University. Partners include the London School of Hygiene and Tropical Medicine, University of Florida, and Great Lakes University of Kisumu. The project began in September 2006.

SWASH+ has three primary objectives:

1. Identify, develop, and test innovative approaches to school- and community-based water, sanitation, and hygiene interventions that promote sustainability and scalability.
2. Provide and test an integrated safe water, sanitation, hygiene-promotion program in schools and communities that maximizes impact, equity, sustainability, and cost-effectiveness.
3. Develop and implement a scalable model for the delivery and financing of safe water, sanitation, and hygiene promotion to schools and communities based on lessons learned and innovative approaches that address the varying conditions found in schools and communities.

SWASH+ includes an applied research and policy agenda. The applied research components of the program were designed to assess the impact of school-based WASH and inform best practice. The applied research

programs have included a cohort of over 200 primary schools and studies to assess:

1) The impact of improved school WASH provision on diarrhoea, absence, and helminths infection;
2) The impact of latrine maintenance, provision of toilet paper, and handwashing soap on pupil absence and latrine use;
3) Household and individual determinants of school absence;
4) The diffusion of hygiene and safe water treatment knowledge and behavior uptake from pupils to households;
5) The reduction in fecal hand contamination through provision of a school-based sanitation and hygiene program;
6) The domains of sustainability of school WASH provision and programming;
7) The function and sustainability of rainwater harvesting facilities at school;
8) Identification of issues surrounding menstrual hygiene management for girls in school; and
9) Anal cleansing practices.

I have been involved in papers that have addressed issues #1-6 above. Aside from publication in academic journals, learning from the program has been used to inform government policy at the provincial and national level and for international advocacy. Advocacy at the national level has focused on additional allocation of funds for school WASH, primarily for consumable

expenses such as soap, and for improved monitoring and evaluation systems that track school WASH conditions.

Internationally, the SWASH+ program has worked with international donors and aid agencies to increase funding for school WASH. I have led a collaboration with UNICEF to increase the visibility of school WASH as a fundamental issue that adversely impacts health and educational attainment of marginalized groups, specifically girls.

3.3. Assessing the Impact of school WASH on diarrhea, helminth Infection and diarrhea

3.3.1 Study design

Within the context of SWASH+, I sought to address the research questions described in Section 2.1. The study design was a cluster-randomized trial using multiple cross-sectional follow-ups of school pupils. The initial district selection and school-selection and randomization were used as a platform to address a number of SWASH+ research questions discussed above. Though the study design was used to answer various SWASH+ research questions, as the in-country field manager (and initial program coordinator) for SWASH+, I managed and led the rapid assessment, school selection and randomization and overall data collection for the study. Therefore, the methods described below are relevant to the SWASH+ program at-large, as well as my dissertation research.

3.4 School selection and site selection

3.4.1 Rapid assessment

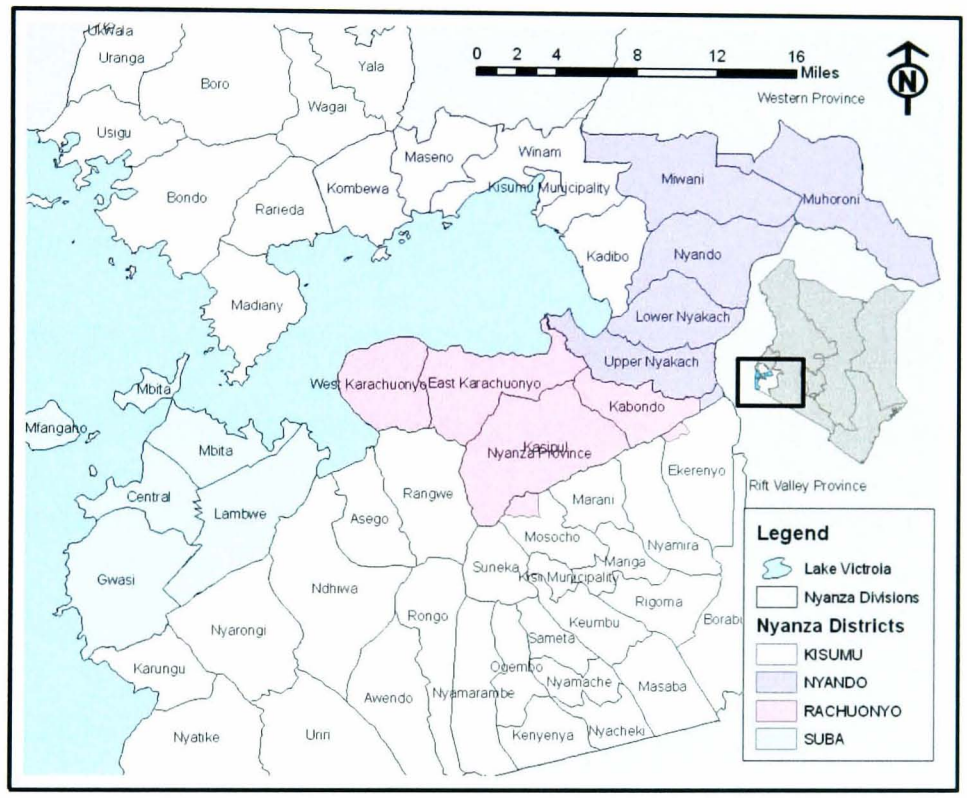
In November 2006, the project partners in close coordination with the Kenya Ministry of Education completed a rapid assessment of school enrollment and water and sanitation infrastructure. The rapid assessment had four primary objectives:

1. To identify and target administrative districts and divisions for the research study;
2. To characterize the current water and sanitation situation in primary schools in selected districts and divisions;
3. To develop eligibility criteria for school-based SWASH+ implementation packages; and
4. To identify specific schools for inclusion in the applied research phase of SWASH+.

I managed all aspects of the rapid assessment, including tool development, coordination with project stakeholder, data collection, and data analysis. The rapid assessment was completed with close collaboration with the Nyanza Province Ministry of Education and the District Education Officers and Zonal Inspectors of what was then Rachuonyo, Suba, Nyando, Kisumu, and Kisumu Municipality. These five target districts were initially chosen based on poverty level and need designated by stakeholders, geographic variability, and presence of other implementing organizations operating in other nearby

districts working on WASH issues. Since 2007, these districts have been split into other districts: Rachuonyo is now Rachuonyo North and Rachuoyno South; Nyando is now Nyando, Nyakatch, and Muhoroni; Kiusumu is now Kisumu East and Kisumu West; Suba is now Mbita and Suba. The administrative districts selected for inclusion in the study, as well as the names of the administrative divisions are shown in Figure 3-2.

Figure 3-2: Map of Nyanza Province and districts selected for SWASH+ program



The rapid assessment survey instrument was drafted in collaboration with the Ministry of Education and SWASH+ partners. Letters explaining the purpose of the survey and duplicate copies of the survey were circulated to every public primary school in the target districts.

The rapid assessment form was a one-page self-assessment completed by the headmaster of each school. The following information was requested:

- Geographic information of the school, including: zone, sub-location, location, division and district
- Enrollment of pupils by class/grade and gender and total number of teachers
- Number of classrooms
- Primary and secondary water sources used by the school in the rainy and dry seasons and distance to the water source
- Number of latrines by gender
- Number of classrooms

Schools were given a total of one month to return the survey to be eligible for the SWASH+ project. Of a total of 1084 schools in the selected districts, 904 (83.3%) of the surveys were returned. Schools in these districts serve 28% of primary school children in Nyanza Province. Data was entered in Microsoft Access 2003 and were cleaned and analyzed using SAS v9.1. Table 1 below shows the number of schools and school children in each of the administrative districts explored in the rapid assessment.

Table 3-1: Eligible schools in Nyanza Province, 2007

(Source: SWASH+ Rapid Assessment Report (2007))

Districts	Division	Zones	Number of Schools			Pupils Enrolment		
			Public	Private	Totals	Boys	Girls	Totals
Kisumu	4	10	189	6	195	29,823	28,865	58,688
Kisumu Municipality	3	9	114	44	158	38,557	37,497	76,054
Nyando	6	15	286	11	297	47,037	45,476	92,513
Rachuonyo	4	18	325	21	346	55,147	51,189	106,336
Suba	5	9	170	13	183	25,880	23,815	49,695
Totals	22	61	1,084	95	1,179	196,444	186,842	383,286

3.4.2 District and School Eligibility Criteria

For logistical reasons the SWASH+ program was not able to include schools from all Districts and Divisions in the sampling frame of the study. Therefore, program stakeholders used available information to refine the study area. Selection for the SWASH+ study area included secondary data on poverty level; rapid assessment data on school latrine and improved water source access; previous and on-going WASH programs; current water, sanitation, and hygiene programming by other organizations in the region; and logistical constraints.

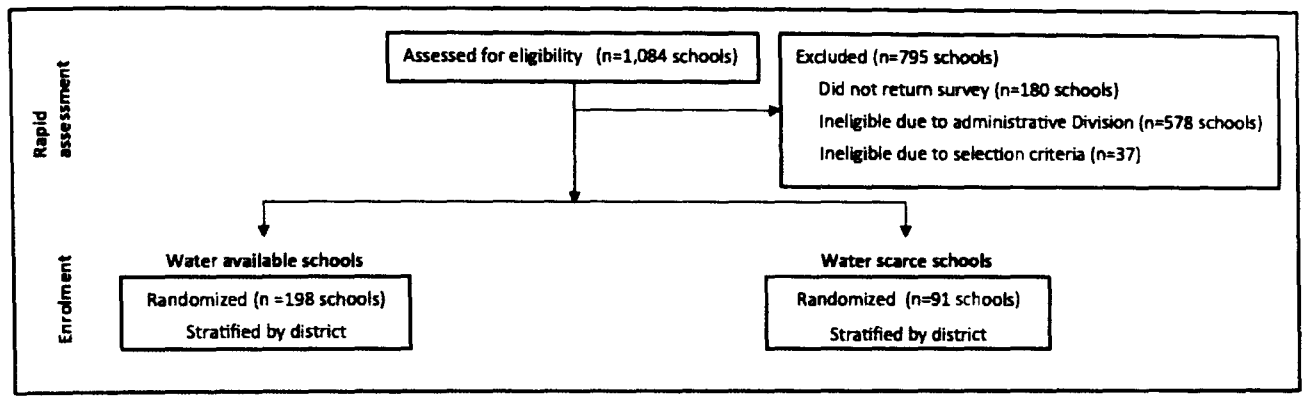
For sake of equity and logistical feasibility, we selected three geographic clusters that consisted of contiguous divisions. In total, eight divisions (divisions are administrative units within a district) within four districts were selected for inclusion in the applied research program. Contiguous divisions were assigned to three geographic research strata: Nyando/Kisumu Districts (Muhoroni and Miwani Division / Kadibo Division), Rachuonyo District (East Karachuonyo and Kabondo Divisions), and Suba District (Gwassi, Central, and Lambwe Divisions).

Eligibility criteria to determine which schools and communities receive which packages were developed by SWASH+ partners in collaboration with representatives from the Government of Kenya. Eligible schools were divided into two groups based on results from the rapid assessment regarding access to drinking water during the dry season and access to sanitation.

- **"Water available" schools:** Schools with access to any water source in the dry season within one kilometer of the school were selected into the "water available" group. No restrictions were placed on the type of water source. Additionally, schools were ineligible unless they exceeded the Government of Kenya (GoK) recommended ratios of 25 girl pupils per latrine and 30 boy pupils per latrine.
- **"Water scarce" schools**: Schools without access to an improved water source during the dry season within one kilometer of the school or access to any water source within two kilometers of the school. Eligibility was also restricted to schools not meeting the government student latrine ratio standards.
- **Excluded schools**: Schools were excluded if they met the Government of Kenya pupil to latrine ratios. Schools that had access to an "improved" water source between 1-2 kilometers from the school were not eligible for the study, since they had sources deemed too far to supply water for handwashing and water treatment on a daily basis and did not have sufficiently poor access, according to the local water authority, to warrant a new source. These schools were eligible for other improvements, but not the research study.

Of the 1,084 schools in the initial target area, 180 (16%) did not return the survey and 615 (57%) were located outside the final target area. Water "available" schools in the three target research clusters included 198 eligible schools, while there were 91 eligible water "scarce" schools (Figure 3-3).

Figure 3-3: School eligibility and enrollment



3.4.3 Intervention components

There were three intervention "packages" designed by the implementation partners. The components of the packages had been developed through best practices by the key implementing partners CARE – Kenya, Water.org (formally WaterPartners International), and Sustainable Aid in Africa. Though each of these partners have worked on WASH issues in western Kenya for over 10 years, they had been brought together in 2005 as part of a collaboration between the Millennium Water Alliance (Washington, D.C.) and the Coca-Cola East Africa Foundation. The implementing partners developed the components of the intervention. Researchers had limited input into the intervention components, with the exception that they recommended that schools should be grouped by the "packages" of resources they received: (a) hygiene promotion and water treatment; (b) sanitation improvements, and (c) provision of water.

The components of the three packages were as follows:

- **Hygiene promotion and water treatment:** Schools assigned to this intervention group received water treatment technology, handwashing hardware, and behavior change education. Water treatment technology included a one-year supply of WaterGuard, a 1.5% chlorine-based point-of-use water disinfectant[1] locally promoted by Population Services International (O'Reilly et al., 2008). Schools were provided four pre-fabricated plastic 60 Liter drinking water storage containers with narrow mouth, lid, and a tap. Handwashing hardware included four 60 Liter locally-available buckets with a lid, tap, and a metal stand. Behavior change and hygiene education included training of one teacher and one parent on the school management committee in (a) behavior change education, (b) hygiene education, and (c) the handwashing and water treatment technologies provided to the school. As part of the hygiene promotion, schools were encouraged to develop a plan to purchase soap for handwashing, as well as water treatment products when the free supply was finished.
- **Latrine provision:** Schools received sanitation improvements in the form of new sanitation facilities and sanitation training and education. The objective was to provide a sufficient number of latrines to bring schools to the GoK standard, with a maximum of seven new latrines.

---

[1]http://www.akvo.org/wiki/index.php/Chlorine_%28Sodium_Hypochlorite%29. Accessed April 25th, 2011

Latrines were double-vaulted, lined ventilated improved pit (VIP) latrines with concrete or plastic superstructures[2]. A VIP latrine has three necessary components: a vent pipe, a screen affixed to the top of the pipe, and darkness inside the latrine. The vent pipe is designed to use the airflow above the structure to reduce the smell within the latrine stall. The screen and darkness inside the latrine are components designed to reduce flies that have entered to escape the pit and potentially contaminate food. Community members were trained on latrine construction and maintenance.

- **Water supply:** Water supply was provided either within the school grounds by a drilled borehole or in the community with piped access guaranteed to the school[3]. In areas where construction of boreholes was not feasible due to subsurface conditions, rainwater catchment systems were constructed. The systems were $60m^3$ rebar enforced concrete tanks designed to last through the dry season[4].

3.4.3 Package allocation

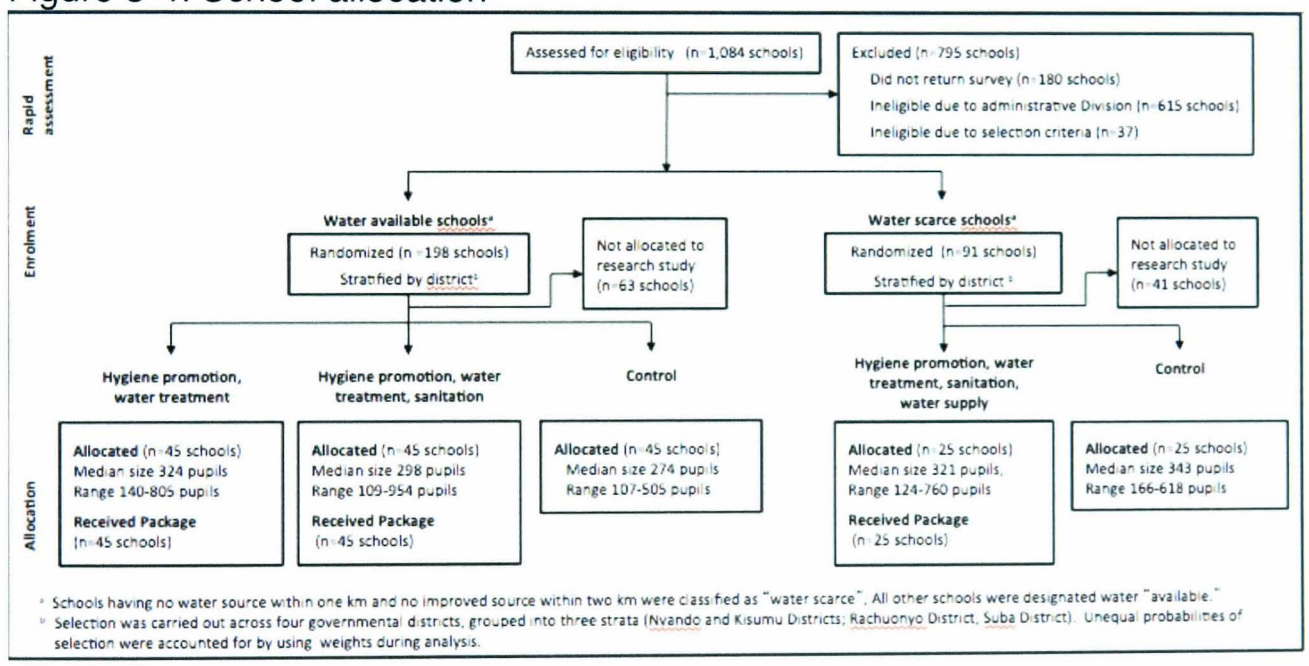
The flow diagram through phases of parallel allocation as part of the cluster randomized study design is shown in Figure 3-4 . Schools in "water available"

---

[2]http://www.akvo.org/wiki/index.php/Double_Ventilated_Improved_Pit. Accessed April 25th, 2011
[3]http://www.akvo.org/wiki/index.php/Jetting_-_Engine_powered_rotary_jetting. Accessed April 25th, 2011
[4]http://www.akvo.org/wiki/index.php/Rainwater_harvesting. Accessed April 25th, 2011

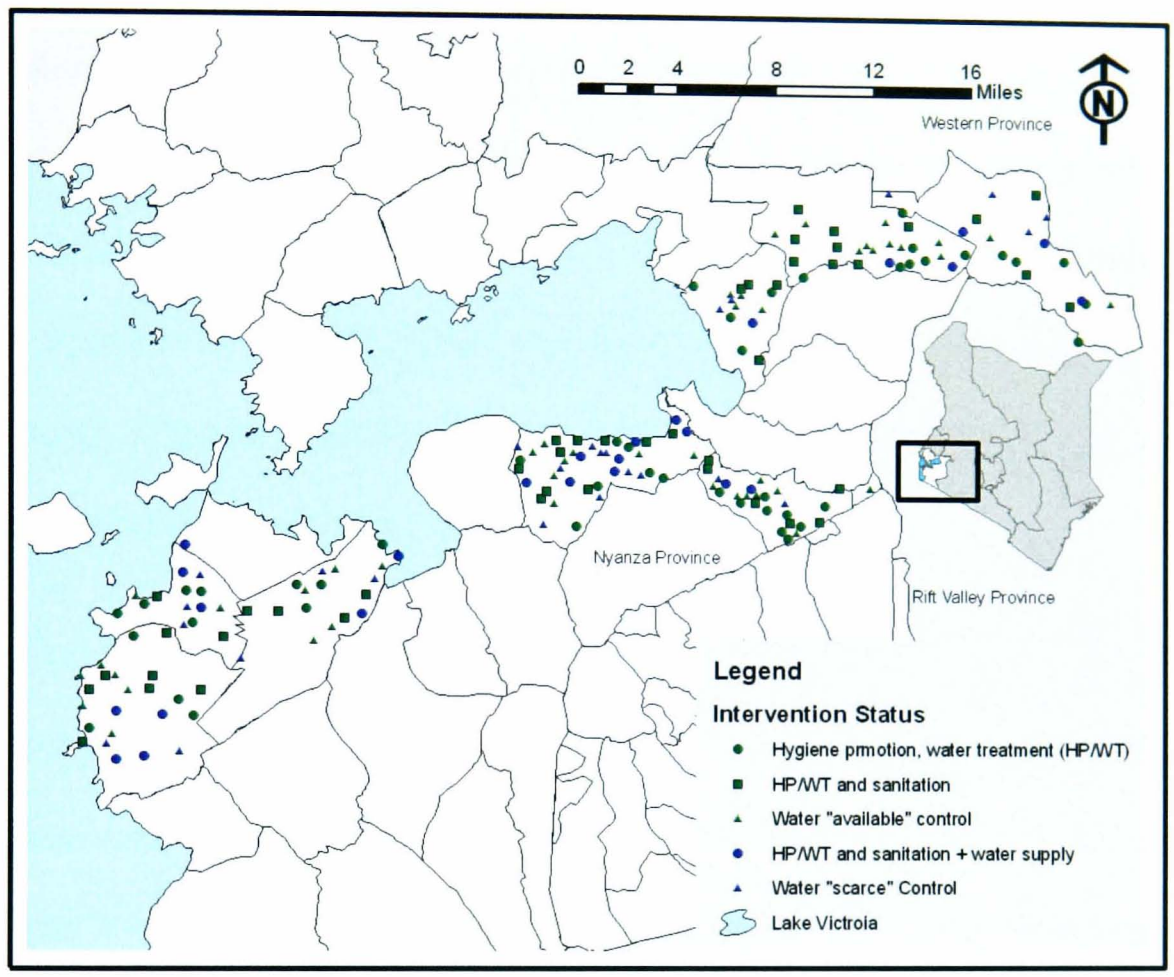
group were eligible to be included in one of three study arms: 1) Hygiene promotion, water treatment, and behavior change education only; 2) hygiene promotion, water treatment, and behavior change *plus* sanitation provision; or 3) control. Of the 198 "water available" schools, 135 were randomly allocated to these three arms, stratified by geographic cluster. Of the 91 schools "water scarce" schools during the dry season, 50 were assigned to either receive the full slate of interventions – hygiene promotion, water treatment, hygiene education, sanitation provision, and water supply – or controls that received no intervention.

Figure 3-4: School allocation



A map showing the location and allocation assignments of schools as part of the SWASH+ cluster randomized trial is shown in Figure 3-5.

Figure 3-5: Map of schools selected for the cluster randomized trial



3.4.4 Considerations for deworming within the study population

Per our study protocol, children in all schools regardless of intervention status received deworming medication at baseline and following two data collection rounds over a two-year period.

As discussed in the previous chapter, recent studies in Western Kenya have revealed that deworming can reduce absence by nearly 25% (Miguel and Kremer, 2004). These findings have implications for the research discussed

herein, as our findings must be considered in the context of reductions in absence due to the deworming that was provided in all the schools. Miguel and colleagues report a 7 percentage point drop (25% reduction) in absence. As such, we might expect a secular reduction in absence in our study population and any results found would mean a reduction in absence beyond what could be expected in a deworming program alone. The results of the WASH intervention may be amplified by the deworming program, as found by Esrey (Esrey et al., 1991). Given the cost-effective benefits established for deworming, it seems pointless to conduct a study on WASH in schools that does not build on a framework for deworming.

Our rationale for conducting the CRT to show reductions in reinfection with STH following deworming are based on worm biology and public health relevance. Given the lifespan of worms in the human body and the short timeframe for the study (two years), we would be unlikely to see reductions in STH infection without deworming. Echoing the discussion above, given the cost-effectiveness of deworming and the move towards population-level deworming campaigns, our objective is to evaluation the effect of a school WASH program in this context.

Given the above discussion of deworming, the applicability of Miguel's findings do need to be considered in appropriate context (Miguel and Kremer, 2004). Though conducted geographically near to our study site, baseline worm infection rates found as part of their study are considerably higher than what we found in our study population for Hookworm (77%), *A. lumbricoides*

(42%), *T. trichiura* (55%), and *S. mansoni* (22%). The true impact of deworming alone to reduce absence and even diarrhoea is not known.

3.5 Measures of effect

The primary impact measures of effect include diarrhoea, soil-transmitted helminths infection, and absence. Secondary impacts of interest included anemia, schistosomiasis, enrollment, and test scores. When possible, we used objective, unbiased measures of effect, rather than subjective indicators. Potential types of bias considered are *recall bias*, where respondents are likely to forget the correct response over time, and *reporting/response bias*, when respondents are likely to misrepresent the true response either to please the researcher with the "correct" response or because the respondent does not want to relay the true information. Challenges with bias and subjectivity of measurement are discussed below.

3.5.1 Diarrhoea

Period prevalence of diarrhoea was assessed using self-report for cases in the previous one week. Duration of diarrhoeal episodes was also calculated using self-report. The case definition of diarrhoea was 3 or more loose or watery stools over a 24-hour period (Baqui et al., 1991). There are two key limitations to self-reporting of diarrhoeal symptoms: measurement subjectivity and recall bias.

Subjective measurements of self-reported disease morbidity are problematic, regardless of the disease or symptom. In a study from Nepal, researchers

found that while morbidities such as ear infection and measles were highly correlated with clinical diagnoses, care-giver report of same-day diarrheal illness was poorly correlated with clinical diagnoses (Katz et al., 1998). In fact, caregiver-reported cases of diarrhoea under-estimated the clinical diagnoses. While understanding and accounting for the underestimation of disease burden is critical for extrapolating morbidity estimates for a population, in the context of our study design, we were primarily interested in the difference in reported cases of diarrhoea between pupils in intervention and control groups. Thus, the key limitation for this measurement is not variations in individual definitions of a subjective measure like diarrhoea.

Various studies of caregiver recall bias for reported diarrhoea among young children have revealed under-estimates as recall period increases (Alam et al., 1989, Ramakrishnan et al., 1998, Byass and Hanlon, 1994, Feikin et al., 2010). Though recall periods of 2-3 days are typically used, severe diarrhoea is not subject to the same level of recall bias (Zafar et al., 2010). Recall bias falls less sharply with self-reported diarrhoeal illness as compared to parent-reported measures (Feikin et al., 2010). A recall period of 4 days in rural Kenya was recommended for precision instead of a two-week recall (Feikin et al., 2010). Since we used pupil self-report, we concluded that the improvement in power to detect a difference between the intervention and control was more beneficial than the underestimation of less severe cases of diarrhoea. Since we don't have any reason to believe that recall bias won't be similar between intervention and control groups, the bias will be towards the null.

One potential limitation of self-reported diarrhoea that might bias the estimate of effect away from the null is reporting bias, if pupils in intervention schools were less likely to report cases of diarrhea than those in control schools. The recall period used will not affect the response bias; rather, there is a need to use more objective measures as proxies for diarrhoeal disease burden. The few potential proxies that have been proposed in recent years to assess effects of poor WASH access - such as weight for age Z-scores, tropical enteropathy, and stool microscopy – remain untested (Kotloff, 2008, Schmidt et al., 2009, Humphrey, 2009). So, self-reporting of diarrhoea remains a valid measure of effect in intervention studies.

3.5.2 Soil-transmitted helminths

Intestinal nematode infections quantified in this study included *Ascaris lumbricoides* (roundworm), *Trichuris trichiura* (whipworm), and *Necator americanus* and *Ancylostoma duodenale* (hookworm). As discussed previously, these are the most pervasive STHs. Stool samples were collected from enrolled pupils and processed using the Kato-Katz technique (Katz et al., 1972). Kato-Katz is a standard parasitological approach to establishing the presence of species-specific ova in low-income settings (Luoba et al., 2005, Mascarini-Serra et al., 2010, Gunawardena et al., 2005). Though other approaches may have better sensitivity, they were infeasible given the associated costs and training needs in a low-income setting (Goodman et al., 2007).

A count of helminth ova is used as a proxy for intensity of infection within the sampled individual, but is not a direct measure of worm burden (Keiser and Utzinger, 2008, Hotez et al., 2006). Two slides were made from each stool sample and read by separate laboratory technicians. If readings differed by more than 10%, each slide was reread. The final number of eggs for each pupil was the mean of the two measurements. Since the amount of feces used for each slide is standardized as 1/24th of a gram, the count for each species of helminths are multiplied by 24 to get a measure of eggs per gram of feces.

Infection of secondary importance to this research was *Schistosoma mansoni* (schistosomiasis), since it is not directly related to WASH access, but more associated with water collection activities in certain bodies of water. In Nyanza Province, since infection with *S. mansoni* is associated with proximity to Lake Victoria, we did not expect that our intervention of improving WASH access at school would be sufficient to reduce schistosomiasis using our study design. Though resulting measurements are reported herein, data were collected primarily in order to report findings to government stakeholders.

Data collection, followed by deworming was to be completed every six months per the Government of Kenya health policy. This policy is not practically enforced due to budget constraints. However, we were not able to extend the reinfection study much beyond 10 months. Though it would have been ideal to test for reinfection multiple times without deworming, we did not think

denying treatment was ethically sound, even for the benefit of improved study power.

3.5.3 Absence

Our primary measure of absence was pupil self-reporting for the previous two weeks of school. Children were asked if they were absent from school in the previous two weeks that school was in session, if the absence was due to illness, if the absence was due to another reason (and what that reason was), and the number of days of absence. Absence was defined as missing either the morning or afternoon session of a single day of school.

Previous studies in Kenya have used either teacher-reported roll-call records to assess absence or researcher-led roll call (O'Reilly et al., 2008, Miguel and Kremer, 2004). Formative research revealed severe challenges with using teacher-reported data due to data quality concerns and reporting bias. School registries typically had days or even weeks missing. In some cases, there was evidence the entire months had been filled in at once.

Researcher-led roll call is when a research staff member records the roll-call during the school day independent of the teacher's typical roll call. Researcher-led roll call was utilized only at follow-up and is considered a secondary measure. Absence of a single day using the roll-call method provides more precision, but it also reduces the power compared to a two-week period prevalence. Formative research revealed that children can correctly recall absence in the previous two weeks with 95% accuracy

(Freeman, unpublished data). Due to sample size and logistical constraints, we elected to use pupil-reported absence.

3.5.4 Anemia

Anemia was a secondary measure of effect, and the study was not powered to detect a difference in anemia levels between pupils in intervention and control schools. Anemia was assessed using capillary haemoglobin levels from pupils following collection of stool samples. Haemoglobin concentration was estimated to an accuracy of 1 g/L using a portable WBC system (Hemocue Ltd, Cypress, CA). Anaemia was defined as a haemoglobin concentration <12 g/dL for children aged 12-14 years and <11.5 g/dL for children aged 5-11 years (WHO et al., 2001). Children with anaemia (<10.0 g/dL) were provided letters from a Government of Kenya Public Health Nurse prescribing iron tablets to be provided at the nearest dispensary.

3.5.5 Enrollment

Enrollment data were collected from official school registries. These numbers for enrolled boys and girls are often on the walls of the school. The only concern with the accuracy of these data is that official enrollment may be inflated to include pupils who sign up for the school, but never attend. Consequently, the enrollment numbers may be slightly inflated by a few students in each class.

3.5.6 Test scores

Test scores, stratified by gender, were collected from the official Kenya Certificate of Primary Education exam administered to pupils graduating from primary school (grade 8). This test is standardized across all schools in the country and is administered in December of each year. The limitation of this measurement is that it is only applicable to the eldest class. Additionally, anecdotal evidence revealed that children who are not expected to pass the exam are sometimes pressured to skip the test in order to enhance the image of the school.

3.6 Sample size

A total of 185 schools were included in the initial cluster randomized trial. The sample sizes for each sub-study are discussed in the individual chapters (4-7) containing the proposed papers intended for publication of the basic results of the research.

3.7 Data collection

Data for this research project was collected between January 2007 and March 2009. Though many studies use longitudinal follow-up for studies, we employed multiple cross-sectional follow-up surveys for our study. The key reason was that over the three-year study period, due to high turnover in the student population and graduation, we would have had considerable loss to follow-up in our cohort. Caregivers are able to send their children to any public primary school in Kenya, and it was reported to us that the turnover rate was over 20% per year. Though this statistic was not able to be

confirmed, the increased sample size needed to accommodate a conservative estimate of loss to follow-up would have been logistically infeasible. Similarly, due to graduation, we would not have been able to enroll children in grades 6, 7 or 8. Enrolling only younger students would have been a considerable limitation to our study. Since we used a cluster design and schools were the unit of randomization, we concluded that random selection of children at each study visit was most feasible.

The timeline for specific data collection activities for SWASH+ is shown in Figure 3-6, with data collection relevant to this thesis shown in color. Data collection included structured interviews, structured observation, use of school data, and stool sampling. The specific data collection methods are discussed in greater detail in individual chapters. Below is an overview of the different data collection components data collected as part of this research.

School-level data: Trained enumerators completed a detailed facility survey at each of the 185 schools included in the cluster-randomized trial. Head teachers were interviewed about WASH access at the school, ongoing hygiene education, the activities of the school health club, new WASH facility construction, engagement of the school management committee regarding WASH-related issues, and engagement with other non-governmental organizations providing WASH infrastructure or education. Observations were conducted on the availability of drinking water, handwashing water, presence of soap, and the number and conditions of latrines. Stored water was tested for chlorine residual using the OTO method (www.aquachem.com).

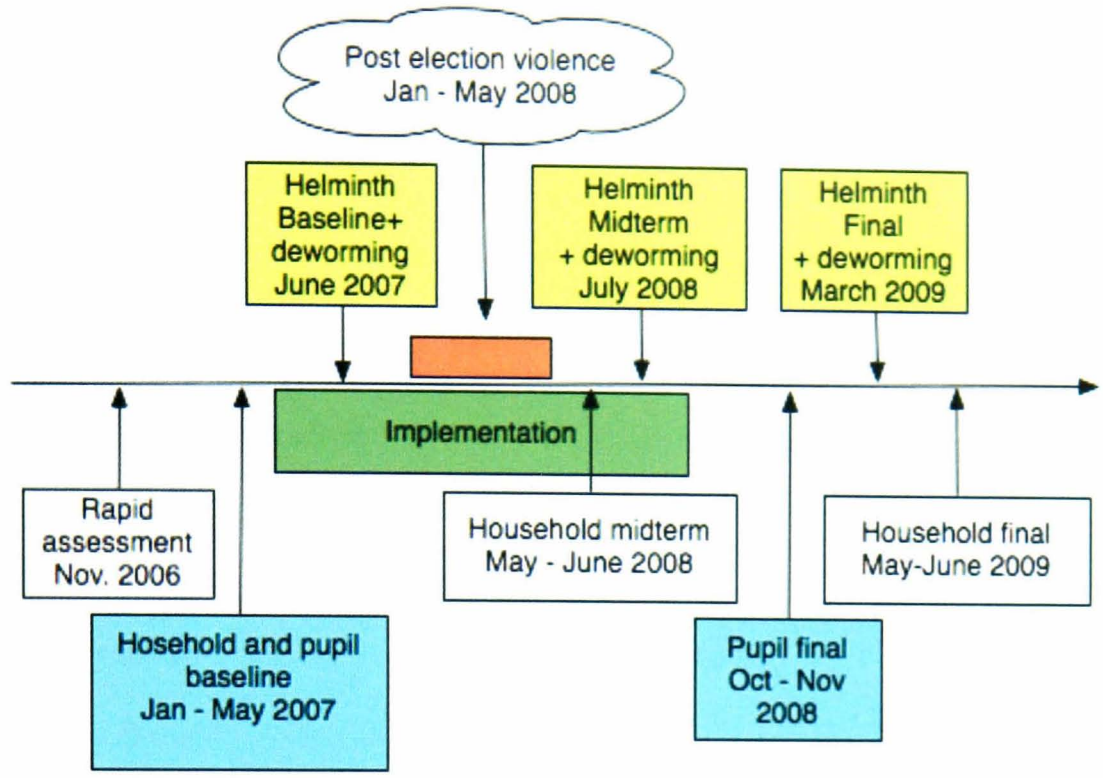
Enrollment, teacher-recorded roll-call, and Kenya Certificate of Primary Education test scores were collected from school records when available.

Pupil-level data: Enumerators completed a detailed survey of pupil knowledge, attitudes, and practices regarding water, sanitation, and handwashing. Pupils were also asked about WASH conditions at school. Pupils were asked about absences from school in the previous two weeks, duration of absence, and causes of absence, as well as the number of days of diarrhoea in the previous 7 days. These data were collected at 185 schools as part of the full cluster-randomized trial.

In a sub-sample of 40 schools, pupils were selected to submit stool samples and to undergo a pinprick blood draw to test for anemia. This was done during data collection rounds. At the final evaluation, these pupils were also given a structured interview similar to the one discussed above to ascertain pupil knowledge, attitudes, and practices.

Household-level data collection: Structured interviews and observations were conducted at homes of pupils selected during the second follow-up data collection round for helminth sampling. Mothers of selected pupils were asked about WASH knowledge, attitudes, and practices. Maternal heads of household were interviewed. Enumerators completed a series of observations on household sanitation facilities, handwashing facilities, and household possessions.

Figure 3-6: Data collection timeline



3.8 Ethics

Ethics approval was obtained from the Institutional Review Board of Emory University in Atlanta, GA; the Ethical Committee of London School of Hygiene and Tropical Medicine, United Kingdom; and the Ethical Review Committee of Great Lakes University of Kisumu, Kenya. Permission for the study was obtained from the Government of Kenya Ministries of Health, Water, and Education.

3.9 References for Chapters 1-3

ADAMS, E. J., STEPHENSON L. S., LATHAM, M. C. & KINOTI, S. N. 1994. Physical activity and growth of Kenyan school children with hookworm, Trichuris trichiura and Ascaris lumbricoides infections are improved after treatment with albendazole. *J Nutr,* 124, 1199-206.

ALAM, N., HENRY, F. J. & RAHAMAN, M. M. 1989. Reporting errors in one-week diarrhoea recall surveys: experience from a prospective study in rural Bangladesh. *Int J Epidemiol,* 18, 697-700.

ALBONICO, M., SMITH, P. G., ERCOLE, E., HALL, A., CHWAYA, H. M., ALAWI, K. S. & SAVIOLI, L. 1995. Rate of reinfection with intestinal nematodes after treatment of children with mebendazole or albendazole in a highly endemic area. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 89, 538-41.

ALBONICO, M., STOLTZFUS, R. J., SAVIOLI, L., CHWAYA, H. M., D'HARCOURT, E. & TIELSCH, J. M. 1999. A controlled evaluation of two school-based anthelminthic chemotherapy regimens on intensity of intestinal helminth infections. *International Journal of Epidemiology,* 28, 591-6.

ALBONICO, M., STOLTZFUS, R. J., SAVIOLI, L., TIELSCH, J. M., CHWAYA, H. M., ERCOLE, E. & CANCRINI, G. 1998. Epidemiological evidence for a differential effect of hookworm species, Ancylostoma duodenale or Necator americanus, on iron status of children. *Int J Epidemiol,* 27, 530-7.

ALDINGER, C., ZHANG, X.-W., LIU, L.-Q., PAN, X.-D., YU, S.-H., JONES, J. & KASS, J. 2008. Changes in attitudes, knowledge and behavior associated with implementing a comprehensive school health program in a province of China. *Health Education Research.*

ALIBHAI, K. & AHMAD, T. Promotion of healthier behaviors through school children. 27th WEDC Conference. People and systems for water, sanitation and health, 2001 Lusaka, Zambia.

ARFAA, F., SAHBA, G. H., FARAHMANDIAN, I. & JALALI, H. 1977. Evaluation of the effect of different methods of control of soil-transmitted helminths in Khuzestan, southwest Iran. *Am J Trop Med Hyg,* 26, 230-3.

ASAOLU, S. O. & OFOEZIE, I. E. 2003. The role of health education and sanitation in the control of helminth infections. *Acta Trop,* 86, 283-94.

ASAOLU, S. O., OFOEZIE, I. E., ODUMUYIWA, P. A., SOWEMIMO, O. A. & OGUNNIYI, T. A. 2002. Effect of water supply and sanitation on the prevalence and intensity of Ascaris lumbricoides among pre-school-age children in Ajebandele and Ifewara, Osun State, Nigeria. *Trans R Soc Trop Med Hyg,* 96, 600-4.

BAIRD, S., HAMORY-HICKS, J., KREMER, M. & MIGUEL, E. 2011. Worms at Work: Long-run Impacts of Child Health Gains. *unpublished working paper.* Berkeley: University of California - Berkeley.

BAQUI, A. H., BLACK, R. E., YUNUS, M., HOQUE, A. R., CHOWDHURY, H. R. & SACK, R. B. 1991. Methodological issues in diarrhoeal diseases epidemiology: definition of diarrhoeal episodes. *Int J Epidemiol,* 20, 1057-63.

BARRETO, M. L., GENSER, B., STRINA, A., TEIXEIRA, M. G., ASSIS, A. M., REGO, R. F., TELES, C. A., PRADO, M. S., MATOS, S., ALCANTARA-NEVES, N. M. & CAIRNCROSS, S. 2010. Impact of a citywide sanitation program in Northeast

Brazil on intestinal parasites infection in young children. *Environ Health Perspect,* 118, 1637-42.

BARRETO, M. L., GENSER, B., STRINA, A., TEIXEIRA, M. G., ASSIS, A. M., REGO, R. F., TELES, C. A., PRADO, M. S., MATOS, S. M., SANTOS, D. N., DOS SANTOS, L. A. & CAIRNCROSS, S. 2007. Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies. *Lancet,* 370, 1622-8.

BARTRAM, J. & CAIRNCROSS, S. 2010. Hygiene, sanitation, and water: forgotten foundations of health. *PLoS Med,* 7, e1000367.

BEASLEY, N. M., TOMKINS, A. M., HALL, A., KIHAMIA, C. M., LORRI, W., NDUMA, B., ISSAE, W., NOKES, C. & BUNDY, D. A. 1999. The impact of population level deworming on the haemoglobin levels of schoolchildren in Tanga, Tanzania. *Tropical Medicine & International Health,* 4, 744-50.

BEHRMAN, J. R. & ROSENZWEIG, M. R. 2002. Does increasing women's schooling raise the schooling of the next generation? *Applied Economic Review,* 92, 323-334.

BETHONY, J., BROOKER, S., ALBONICO, M., GEIGER, S. M., LOUKAS, A., DIEMERT, D. & HOTEZ, P. J. 2006. Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. *Lancet,* 367, 1521-32.

BLAKELY, T., HALES, S., KIEFT, C., WILSON, N. & WOODWARD, A. 2005. The global distribution of risk factors by poverty level. *Bull World Health Organ,* 83, 118-26.

BLANTON, E., OMBEKI, S., OLUOCH, G., MWAKI, A., WANNEMUEHLER, K. & QUICK, R. 2010. Evaluation of the role of school children in the promotion of point-of-use water treatment and handwashing in schools and households--Nyanza Province, Western Kenya, 2007. *American Journal of Tropical Medicine and Hygiene,* 82, 664-671.

BOSCHI-PINTO, C., VELEBIT, L. & SHIBUYA, K. 2008. Estimating child mortality due to diarrhoea in developing countries. *Bull World Health Organ,* 86, 710-7.

BOWEN, A., MA, H., OU, J., BILLHIMER, W., LONG, T., MINTZ, E., HOEKSTRA, M. & LUBY, S. P. 2007. A cluster-randomized controlled trial evaluating the effect of a handwashing-promotion program in Chinese primary schools. *American Journal of Tropical Medicine & Hygiene,* 76, 1166-1173.

BRANHAM, D. 2004. The wise man builds his house upon the rock: The effects of inadequate school building infrastructure on student attendance. *Social Science Quarterly,* 85, 1112-1128.

BROOKER, S. 2010. Estimating the global distribution and disease burden of intestinal nematode infections: adding up the numbers--a review. *Int J Parasitol,* 40, 1137-44.

BROOKER, S., BETHONY, J. & HOTEZ, P. J. 2004. Human hookworm infection in the 21st century. *Adv Parasitol,* 58, 197-288.

BROOKER, S. & BUNDY, D. A. P. 2008. Soil-transmitted helminths (geohelminths). *In:* COOK, G. C., ZUMLA, A.I. (ed.) *Manson's Tropical Diseases.* 22nd ed ed. London: Elsevier.

BROOKER, S. & CLEMENTS, A. C. 2008. Spatial heterogeneity of parasite co-infection: Determinants and geostatistical prediction at regional scales. *Int J Parasitol.*

BROOKER, S., KABATEREINE, N. B., SMITH, J. L., MUPFASONI, D., MWANJE, M. T., NDAYISHIMIYE, O., LWAMBO, N. J., MBOTHA, D., KARANJA, P., MWANDAWIRO, C., MUCHIRI, E., CLEMENTS, A. C., BUNDY, D. A. & SNOW, R. W. 2009. An updated atlas of human helminth infections: the example of East Africa. *Int J Health Geogr,* 8, 42.

BUNDY, D. A. & GUYATT, H. L. 1996. Schools for health: Focus on health, education and the school-age child. *Parasitol Today,* 12, suppl 1-16.

BYASS, P. & HANLON, P. W. 1994. Daily morbidity records: recall and reliability. *Int J Epidemiol,* 23, 757-63.

CAIRNCROSS, S., BLUMENTHAL, U., KOLSKY, P., MORAES, L. & TAYEH, A. 1996. The public and domestic domains in the transmission of disease. *Trop Med Int Health,* 1, 27-34.

CAIRNCROSS, S., HUNT, C., BOISSON, S., BOSTOEN, K., CURTIS, V., FUNG, I. C. & SCHMIDT, W. P. 2010. Water, sanitation and hygiene for the prevention of diarrhoea. *Int J Epidemiol,* 39 Suppl 1, i193-205.

CARROLL, H. C. M. 2011. The Effect of Pupil Absenteeism on Literacy and Numeracy in the Primary School. *School Psychology International,* 31, 115-130.

CAUCHEMEZ, S., BHATTARAI, A., MARCHBANKS, T. L., FAGAN, R. P., OSTROFF, S., FERGUSON, N. M. & SWERDLOW, D. 2011. Role of social networks in shaping disease transmission during a community outbreak of 2009 H1N1 pandemic influenza. *Proc Natl Acad Sci U S A,* 108, 2825-30.

CHAN, M. S. 1997. The global burden of intestinal nematode infections--fifty years on. *Parasitol Today,* 13, 438-43.

CHAN, M. S., MEDLEY, G. F., JAMISON, D. & BUNDY, D. A. 1994. The evaluation of potential global morbidity attributable to intestinal nematode infections. *Parasitology,* 109 (Pt 3), 373-87.

CHEN, L., JENNISON, B. L., YANG, W. & OMAYE, S. T. 2000. Elementary school absenteeism and air pollution. *Inhal Toxicol,* 12, 997-1016.

CLASEN, T., SCHMIDT, W.-P., RABIE, T., ROBERTS, I. & CAIRNCROSS, S. 2007. Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *British Medical Journal,* 334.

CLASEN, T., SUGDEN, S. 2009. Water and Sanitation (Chapter 2.7), in Beaglehole R. et al. (eds.), Oxford Textbook of Public Health. Oxford: Oxford University Press.

CLASEN, T. F., BOSTOEN, K., SCHMIDT, W. P., BOISSON, S., FUNG, I. C., JENKINS, M. W., SCOTT, B., SUGDEN, S. & CAIRNCROSS, S. 2010. Interventions to improve disposal of human excreta for preventing diarrhoea. *Cochrane Database Syst Rev,* 6, CD007180.

CORRALES, L. F., IZURIETA, R. & MOE, C. L. 2006. Association between intestinal parasitic infections and type of sanitation system in rural El Salvador. *Trop Med Int Health,* 11, 1821-31.

CROMPTON, D. W. 1999. How much human helminthiasis is there in the world? *Journal of Parasitology,* 85, 397-403.

CROMPTON, D. W. 2001. Ascaris and ascariasis. *Adv Parasitol,* 48, 285-375.

CURTIS, V. & CAIRNCROSS, S. 2003. Effect of washing hands with soap on diarrhoea risk in the community: A systematic review. *The Lancet Infectious Diseases,* 3, 275-281.

DE SILVA, N. R., BROOKER, S., HOTEZ, P. J., MONTRESOR, A., ENGELS, D. & SAVIOLI, L. 2003. Soil-transmitted helminth infections: updating the global picture. *Trends Parasitol,* 19, 547-51.

DICKSON, R., AWASTHI, S., WILLIAMSON, P., DEMELLWEEK, C. & GARNER, P. 2000. Effects of treatment for intestinal helminth infection on growth and cognitive performance in children: systematic review of randomised trials. *Bmj,* 320, 1697-701.

DREIBELBIS, R., GREEN, L., FREEMAN, M., SABOORI, S., MUGA, R. & RHEINGANS, R. 2011. Multi-level assessment of the association of primary school absence with school and household water, sanitation, and hygiene conditions: the influence of gender and household wealth. Atlanta: Emory University.

DYER, D. L. 2001. Does use of an instant hand sanitizer reduce elementary school illness absenteeism? *The Joural of Family Practice,* 50, 64.

EISENBERG, J. N., SCOTT, J. C. & PORCO, T. 2007. Integrating disease control strategies: balancing water sanitation and hygiene interventions to reduce diarrheal disease burden. *Am J Public Health,* 97, 846-52.

ESREY, S. A., FEACHEM, R. G. & HUGHES, J. M. 1985. Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bulletin of the World Health Organization,* 63, 757-772.

ESREY, S. A. & HABICHT, J. P. 1986. Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiologic Reviews,* 8, 117-128.

ESREY, S. A., POTASH, J. B., ROBERTS, L. & SHIFF, C. 1991. Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bull World Health Organ,* 69, 609-21.

FEIKIN, D. R., AUDI, A., OLACK, B., BIGOGO, G. M., POLYAK, C., BURKE, H., WILLIAMSON, J. & BREIMAN, R. F. 2010. Evaluation of the optimal recall period for disease symptoms in home-based morbidity surveillance in rural and urban Kenya. *Int J Epidemiol,* 39, 450-8.

FENTIMAN, A., HALL, A. & BUNDY, D. 2001. Health and cultural factors associated with enrolment in basic education: a study in rural Ghana. *Soc Sci Med,* 52, 429-39.

FEWTRELL, L. & COLFORD, J. M. 2004. Water, Sanitation and Hygiene: Interventions and Diarrhoea, A Systematic Review and Meta-analysis. *In:* PREKER, A. S. (ed.) *Health, Nutrition and Population (HNP) Discussion Paper.* Washington, D.C.: The World Bank.

FEWTRELL, L., KAUFMANN, R. B., KAY, D., ENANORIA, W., HALLER, L. & COLFORD JR, J. M. 2005. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis. *The Lancet Infectious Diseases,* 5, 42-52.

FISHER, J. 2004. The EDUCATION Millennium Development Goal: What water, sanitation and hygiene can do. *WELL Briefing Note.* Leicestershire: WEDC.

FREEMAN, M. & CLASEN, T. 2010. A cluster-randomized trial to assess the impact of a school-based safe water intervention on household adoption of point-of-use water treatment practices in Southern India. . *Am J Trop Med & Hygiene, in press.*

GILLILAND, F. D., BERHANE, K., RAPAPORT, E. B., THOMAS, D. C., AVOL, E., GAUDERMAN, W. J., LONDON, S. J., MARGOLIS, H. G., MCCONNELL, R., ISLAM, K. T. & PETERS, J. M. 2001. The effects of ambient air pollution on school absenteeism due to respiratory illnesses. *Epidemiology,* 12, 43-54.

GOODMAN, D., HAJI, H. J., BICKLE, Q. D., STOLTZFUS, R. J., TIELSCH, J. M., RAMSAN, M., SAVIOLI, L. & ALBONICO, M. 2007. A comparison of methods for detecting the eggs of Ascaris, Trichuris, and hookworm in infant stool, and

the epidemiology of infection in Zanzibari infants. *Am J Trop Med Hyg,* 76, 725-31.

GOTTFRIED, M. A. 2010. Evaluating the Relationship between Student Attendance and Achievement in Urban Elementary and Middle Schools: An Instrumental Variables Approach. *American Educational Research Journal,* 47, 434-465.

GUERRANT, D. I., MOORE, S. R., LIMA, A. A., PATRICK, P. D., SCHORLING, J. B. & GUERRANT, R. L. 1999. Association of early childhood diarrhea and cryptosporidiosis with impaired physical fitness and cognitive function four-seven years later in a poor urban community in northeast Brazil. *Am J Trop Med Hyg,* 61, 707-13.

GUERRANT, R. L., KOSEK, M., LIMA, A. A., LORNTZ, B. & GUYATT, H. L. 2002. Updating the DALYs for diarrhoeal disease. *Trends Parasitol,* 18, 191-3.

GUINAN, M., MCGUCKIN, M. & ALI, Y. 2002. The effect of a comprehensive handwashing program on absenteeism in elementary schools. *American Journal of Infection Control,* 30, 217-20.

GUNAWARDENA, G. S., KARUNAWEERA, N. D. & ISMAIL, M. M. 2004. Socio-economic and behavioural factors affecting the prevalence of Ascaris infection in a low-country tea plantation in Sri Lanka. *Ann Trop Med Parasitol,* 98, 615-21.

GUNAWARDENA, G. S., KARUNAWEERA, N. D. & ISMAIL, M. M. 2005. Effects of climatic, socio-economic and behavioural factors on the transmission of hookworm (Necator americanus) on two low-country plantations in Sri Lanka. *Ann Trop Med Parasitol,* 99, 601-9.

GUYATT, H. 2000. Do intestinal nematodes affect productivity in adulthood? *Parasitology Today,* 16, 153-8.

GYORKOS, T. W., CAMARA, B., KOKOSKIN, E., CARABIN, H. & PROUTY, R. 1996. [Survey of parasitic prevalence in school-aged children in Guinea (1995)]. *Sante,* 6, 377-81.

HAMMOND, B., ALI, Y., FENDLER, E., DOLAN, M. & DONOVAN, S. 2000. Effect of hand sanitizer use on elementary school absenteeism. *Am J Infect Control,* 28, 340-6.

HEMSON, D. 2007. 'The Toughest of Chores': policy and practice in children collecting water in South Africa. *Policy Futures in Education,* 5, 315-326.

HENRY, F. J. 1988. Reinfection with Ascaris lumbricoides after chemotherapy: a comparative study in three villages with varying sanitation. *Trans R Soc Trop Med Hyg,* 82, 460-4.

HOTEZ, P. J., BUNDY, D. A. P., BEEGLE, K., BROOKER, S., DRAKE, L., SILVA, N. D., MONTRESOR, A., ENGELS, D., JUKES, M., CHITSULO, L., CHOW, J., LAXMINARAYAN, R., MICHAUD, C. M., BETHONY, J., CORREA–OLIVEIRA, R., SHU–HUA, X., FENWICK, A. & SAVIOLI, L. 2006. Helminth Infections: Soil–Transmitted Helminth Infections and Schistosomiasis. *Disease Control Priorities in Developing Countries (2nd Edition),ed.* New York: Oxford University Press.

HOUGHTON, F. 2003. The use of primary/national school absenteeism as a proxy retrospective child health status measure in an environmental pollution investigation. *Journal of the Royal Institute of Public Health,* 117, 417-423.

HUMPHREY, J. H. 2009. Child undernutrition, tropical enteropathy, toilets, and handwashing. *Lancet,* 374, 1032-5.

HUNTER, P. 2009. Household Water Treatment in Developing Countries: Comparing Different Intervention Types Using Meta-Regression. *Environmental Science & Technology,* 43, 8991-8997.

HUTTON, G., HALLER, L. & BARTRAM, J. 2007. Global cost-benefit analysis of water supply and sanitation interventions. *J Water Health,* 5, 481-502.

KANOA, B., GEORGE, E., ABED, Y. & AL-HINDI, A. 2006. Evaluation of the Relationship Between Intestinal Parasitic Infection and Health Education Among School Children in Gaza City, Beit-Lahia Village and Jabalia Refugee Camp, Gaza Strip, Palestine. *The Islamic University Journal (Series of Natural Studies and Engineering),* 14, 39-49.

KATZ, J., WEST, K. P., JR., LECLERQ, S. C., THAPA, M. D., KHATRY, S. K., SHRESTA, S. R., PRADHAN, E. K. & POHKREL, R. P. 1998. Agreement between clinical examination and parental morbidity histories for children in Nepal. *J Trop Pediatr,* 44, 225-9.

KATZ, N., CHAVEZ, A. & PELLEGRINO, J. 1972. A simple device for quantitative stool thick-smear technique in Schostosomiasis mansoni. *Rev Inst Med Trop Sao Paulo,* 14, 397-400.

KEISER, J. & UTZINGER, J. 2008. Efficacy of current drugs against soil-transmitted helminth infections: systematic review and meta-analysis. *JAMA,* 299, 1937-48.

KILLEWO, J. Z., CAIRNCROSS, S., SMET, J. E., MAIKWANO, L. F. & VAN ASTEN, H. 1991. Patterns of hookworm and Ascaris infection in Dar es Salaam. *Acta Trop,* 48, 247-9.

KOSEK, M., BERN, C. & GUERRANT, R. L. 2003. The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bulletin of the World Health Organization,* 81, 197-204.

KOTLOFF, K. L. Overview: Global Enterics Multi-Center Study (GEMS). American Society of Tropical Medicine and Hygiene, 2008 New Orleans, LA.

LEVY, K., NELSON, K. L., HUBBARD, A. & EISENBERG, J. N. 2008. Following the water: a controlled study of drinking water storage in northern coastal Ecuador. *Environ Health Perspect,* 116, 1533-40.

LUOBA, A. I., WENZEL GEISSLER, P., ESTAMBALE, B., OUMA, J. H., ALUSALA, D., AYAH, R., MWANIKI, D., MAGNUSSEN, P. & FRIIS, H. 2005. Earth-eating and reinfection with intestinal helminths among pregnant and lactating women in western Kenya. *Tropical Medicine & International Health,* 10, 220-7.

MASCARINI-SERRA, L. M., TELLES, C. A., PRADO, M. S., MATTOS, S. A., STRINA, A., ALCANTARA-NEVES, N. M. & BARRETO, M. L. 2010. Reductions in the prevalence and incidence of geohelminth infections following a city-wide sanitation program in a Brazilian Urban Centre. *PLoS Negl Trop Dis,* 4, e588.

MASSA, K., MAGNUSSEN, P., SHESHE, A., NTAKAMULENGA, R., NDAWI, B. & OLSEN, A. 2009. The effect of the community-directed treatment approach versus the school-based treatment approach on the prevalence and intensity of schistosomiasis and soil-transmitted helminthiasis among schoolchildren in Tanzania. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 103, 31-7.

MEADOWS, E. & SAUX, N. L. 2004. A systematic review of the effectiveness of antimicrobial rinse-free hand sanitizers for prevention of illness-related absenteeism in elementary school children. *BMC Public Health,* 4.

MIGELE, J., OMBEKI, S., AYALO, M., BIGGERSTAFF, M. & QUICK, R. E. 2007. Diarrhea prevention in a Kenyan school through the use of a simple safe water and hygiene intervention. *American Journal of Tropical Medicine & Hygiene,* 76, 351-353.

MIGUEL, E. & KREMER, M. 2004. Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities. *Econometrica,* 72.

MONTRESOR, A., RAMSAN, M., CHWAYA, H. M., AMEIR, H., FOUM, A., ALBONICO, M., GYORKOS, T. W. & SAVIOLI, L. 2001. School enrolment in Zanzibar linked to children's age and helminth infections. *Tropical Medicine and International Health,* 6, 227-231.

MOONIE, S., STERLING, D. A., FIGGS, L. W. & CASTRO, M. 2008. The Relationship between School Absence, Academic Performance, and Asthma Status. *Journal of School Health,* 78, 140-148.

MOORE, S. R., LIMA, A. A., CONAWAY, M. R., SCHORLING, J. B., SOARES, A. M. & GUERRANT, R. L. 2001. Early childhood diarrhoea and helminthiases associate with long-term linear growth faltering. *Int J Epidemiol,* 30, 1457-64.

MORAES, L. R. & CAIRNCROSS, S. 2004. Environmental interventions and the pattern of geohelminth infections in Salvador, Brazil. *Parasitology,* 129, 223-32.

MORTON, J. L. & SCHULTZ, A. A. 2004. Healthy Hands: Use of alcohol gel as an adjunct to handwashing in elementary school children. *Journal of School Nursing,* 20, 161-7.

MURRAY, C. & LOPEZ, A. 1996. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. *Global Burden of Disease and Injury Series Vol. 1 xxxii, 990 p.* Boston, Massachusetts: School of Public Health, Harvard University.

MURRAY, C. J. & LOPEZ, A. D. 1997. Mortality by cause for eight regions of the world: Global Burden of Disease Study. *Lancet,* 349, 1269-76.

MWANGA, J. R., JENSES, B. B., MAGNUSSEN, P. & AAGAARD-HANSEN, J. 2007. School children as health change agents in Magu, Tanzania: a feasibility study. *Health Promotion International,* 23.

NAHAR, Q. & AHMED, R. 2006. Addressing special needs of girls challenges in school. *Second South Asian Conference on Sanitation (SACOSAN-2).* Islamabad, Pakistan.

NIEHAUS, M. D., MOORE, S. R., PATRICK, P. D., DERR, L. L., LORNTZ, B., LIMA, A. A. & GUERRANT, R. L. 2002. Early childhood diarrhea is associated with diminished cognitive function 4 to 7 years later in children in a northeast Brazilian shantytown. *Am J Trop Med Hyg,* 66, 590-3.

NOKES, C. & BUNDY, D. A. 1994. Does helminth infection affect mental processing and educational achievement? *Parasitol Today,* 10, 14-8.

NOKES, C., GRANTHAM-MCGREGOR, S. M., SAWYER, A. W., COOPER, E. S. & BUNDY, D. A. 1992. Parasitic helminth infection and cognitive function in school children. *Proc Biol Sci,* 247, 77-81.

NOKES, C., MCGARVEY, S. T., SHIUE, L., WU, G., WU, H., BUNDY, D. A. & OLDS, G. R. 1999. Evidence for an improvement in cognitive function following treatment of Schistosoma japonicum infection in Chinese primary schoolchildren. *Am J Trop Med Hyg,* 60, 556-65.

O'REILLY, C., FREEMAN, M., RAVANI, M., MIGELE, J., A., M., AYALO, M., S., O., HOEKSTRA, M. R. & E., Q. R. 2008. The impact of a school-based safe water and hygiene programme on knowledge and practices of students and their parents: Nyanza Province, western Kenya, 2006. *Epidemiology & Infection,* 136, 80-91.

OLSEN, A. 2003. Experience with school-based interventions against soil-transmitted helminths and extension of coverage to non-enrolled children. *Acta Trop,* 86, 255-66.

OLSEN, A., SAMUELSEN, H. & ONYANGO-OUMA, W. 2001. A study of risk factors for intestinal helminth infections using epidemiological and anthropological approaches. *J Biosoc Sci,* 33, 569-84.

ONYANGO-OUMA, W., AAGAARD-HANSEN, J. & JENSEN, B. B. 2005. The potential of schoolchildren as health change agents in rural western Kenya. *Soc Sci Med,* 61, 1711-1722.

OSTER, E. & THORNTON, R. 2011. Menstruation, sanitary products, and school attendance: evidence from a randomized evaluation. *American Economics Journal: Applied Economics,* 3.

PAGE, W. H. 1912. The hookworm and civilization: the work of the Rockefeller Sanitary Commission in the southern states. *The World's Work* Garden City, NY: Doubleday, Paige and Co.

PARK, H., LEE, B., HA, E. H., LEE, J. T., KIM, H. & HONG, Y. C. 2002. Association of air pollution with school absenteeism due to illness. *Archives of Pediatrics & Adolescent Medicine,* 156, 1235-1239.

PEARSON, J. & MCPHEDRAN, K. 2008. A literature review of the non-health impacts of sanitation. *Waterlines,* 27, 48-61.

PETER J. HOTEZ, DONALD A. P. BUNDY, KATHLEEN BEEGLE, SIMON BROOKER, LESLEY DRAKE, NILANTHI DE SILVA, ANTONIO MONTRESOR, DIRK ENGELS, MATTHEW JUKES, LESTER CHITSULO, JEFFREY CHOW, RAMANAN LAXMINARAYAN, CATHERINE M. MICHAUD, JEFF BETHONY, RODRIGO CORREA–OLIVEIRA, XIAO SHU–HUA, ALAN FENWICK & LORENZO SAVIOLI 2006. Helminth Infections: Soil–Transmitted Helminth Infections and Schistosomiasis. *Disease Control Priorities in Developing Countries* New York: Oxford University Press.

POSTLETHWAITE, N. 1998. The Conditions of Primary Schools: a pilot study in the least developed countries. *International Review of Education,* 44, 1573-0638.

PRUSS, A., KAY, D., FEWTRELL, L. & BARTRAM, J. 2002. Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental Health Perspectives,* 110, 537-542.

PRUSS-USTUN A & C, C. 2006. Preventing disease through healthy environments – Towards an estimate of the environmental burden of disease. Geneva: World Health Organization.

PRUSS-USTUN, A., BONJOUR, S. & CORVALAN, C. 2008. The impact of the environment on health by country: a meta-synthesis. *Environ Health,* 7, 7.

QUINNELL, R. J., SLATER, A. F., TIGHE, P., WALSH, E. A., KEYMER, A. E. & PRITCHARD, D. I. 1993. Reinfection with hookworm after chemotherapy in Papua New Guinea. *Parasitology,* 106 (Pt 4), 379-85.

RABIE, T. & CURTIS, V. 2006. Handwashing and risk of respiratory infections: a quantitative systematic review. *Trop Med Int Health,* 11, 258-67.

RAJ, S. M., SEIN, K. T., ANUAR, A. K. & MUSTAFFA, B. E. 1997. Effect of intestinal helminthiasis on school attendance by early primary schoolchildren. *Trans R Soc Trop Med Hyg,* 91, 131-2.

RAMAKRISHNAN, R., VENKATARAO, T., KOYA, P. K. & KAMARAJ, P. 1998. Influence of recall period on estimates of diarrhoea morbidity in infants in rural Tamil Nadu. *Indian J Public Health,* 42, 3-6.

RHEINGANS, R., FREEMAN, M., GREENE, L., DREIBELBIS, R. & SABOORI, S. 2009. Can a school-based water, sanitation and hygiene intervention catalyze changes in household behaviors and environment? Evidence from a randomized trial in western Kenya. . *International Research Colloquium of the Network to promote Household Water Treatment and Safe Storage*

RHEINGANS, R. D., DREIBELBIS, R. & FREEMAN, M. C. 2006. Beyond the Millennium Development Goals: Public health challenges in water and sanitation. *Global Public Health,* 1, 31-48.

ROBERTS, L., CHARTIER, Y., CHARTIER, M., TOOLE, M. & RODKA, H. 2001. Keeping water clean in a Malawi refugee camp: A randomized intervention trial. *Bulletin of the World Health Organization,* 79, 280-287.

SAHBA, G. H. & ARFAA, F. 1967. The effect of sanitation on ascariasis in an Iranian village. *J Trop Med Hyg,* 70, 37-9.

SAKTI, H., NOKES, C., HERTANTO, W. S., HENDRATNO, S., HALL, A., BUNDY, D. A. & SATOTO 1999. Evidence for an association between hookworm infection and cognitive function in Indonesian school children. *Trop Med Int Health,* 4, 322-34.

SANDORA, T. J., SHIH, M.-C. & GOLDMANN, D. A. 2008. Reducing Absenteeism From Gastrointestinal and Respiratory Illness in Elementary School Students: A Randomized, Controlled Trial of an Infection-Control Intervention. *Pediatrics,* 121, e1555–e1562.

SCHLIESSMANN, D. J., ATCHLEY, F. O., WILCOMB, M. J., JR. & WELCH, S. F. 1958. Relation of environmental factors to the occurrence of enteric diseases in areas of Eastern Kentucky. *Public Health Monogr,* 54, 1-33.

SCHMIDT, W. P., BOISSON, S., GENSER, B., BARRETO, M., BAISLEY, K., FILTEAU, S. & CAIRNCROSS, S. 2009. Weight-for-age z-score as a proxy marker for diarrhoea in epidemiological studies. *J Epidemiol Community Health.*

SIDIBE, M. A. 2007. Can hygiene be cool and fun? Understanding school children's motivations to use their school toilets and wash their hands with soap in Dakar, Senegal. DrPH.

SIMEON, D. T., GRANTHAM-MCGREGOR, S. M., CALLENDER, J. E. & WONG, M. S. 1995. Treatment of Trichuris trichiura infections improves growth, spelling scores and school attendance in some children. *J Nutr,* 125, 1875-83.

SNEL, M. 2004. The Worth of School Sanitation and Hygiene Education. Delft, the Netherlands: International Water and Sanitation Centre (IRC).

SOMMER, M. 2009. Ideologies of sexuality, menstruation and risk: girls' experiences of puberty and schooling in northern Tanzania. *Cult Health Sex,* 11, 383-98.

SOMMER, M. 2010. Where the education system and women's bodies collide: The social and health impact of girls' experiences of menstruation and schooling in Tanzania. *J Adolesc,* 33, 521-9.

STEPHENSON, L. S. 1994. Helminth parasites, a major factor in malnutrition. *World Health Forum,* 15, 169-72.

STEPHENSON, L. S., HOLLAND, C. V. & COOPER, E. S. 2000a. The public health significance of Trichuris trichiura. *Parasitology,* 121, S73-S95.

STEPHENSON, L. S., LATHAM M. C., ADAMS, E. J., KINOTI, S. N. & PERTET, A. 1993. Physical fitness, growth and appetite of Kenyan school boys with hookworm, Trichuris trichiura and Ascaris lumbricoides infections are improved four months after a single dose of albendazole. *Journal of Nutrition,* 123, 1036-46.

STEPHENSON, L. S., LATHAM M. C., KURZ, K. M., KINOTI, S. N. & BRIGHAM, H. 1989. Treatment with a single dose of albendazole improves growth of Kenyan schoolchildren with hookworm, Trichuris trichiura, and Ascaris lumbricoides infections. *American Journal of Tropical Medicine and Hygiene,* 41, 78-87.

STEPHENSON, L. S., LATHAM, M. C., KINOTI, S. N., KURZ, K. M. & BRIGHAM, H. 1990. Improvements in physical fitness of Kenyan schoolboys infected with hookworm, Trichuris trichiura and Ascaris lumbricoides following a single dose of albendazole. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* 84, 277-82.

STEPHENSON, L. S., LATHAM, M. C. & OTTESEN, E. A. 2000. Malnutrition and parasitic helminth infections. *Parasitology,* 121 Suppl, S23-38.

STOLTZFUS, R. J., ALBONICO, M., CHWAYA, H. M., TIELSCH, J. M., SCHULZE, K. J. & SAVIOLI, L. 1998. Effects of the Zanzibar school-based deworming program on iron status of children. *Am J Clin Nutr,* 68, 179-86.

STOTHARD, J. R., IMISON, E., FRENCH, M. D., SOUSA-FIGUEIREDO, J. C., KHAMIS, I. S. & ROLLINSON, D. 2008. Soil-transmitted helminthiasis among mothers and

their pre-school children on Unguja Island, Zanzibar with emphasis upon ascariasis. *Parasitology,* 135, 1447-55.

SUR, D., SAHA, D. R., MANNA, B., RAJENDRAN, K. & BHATTACHARYA, S. K. 2005. Periodic deworming with albendazole and its impact on growth status and diarrhoeal incidence among children in an urban slum of India. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 99, 261-7.

SWASH+ PROGRAM & CENTER FOR GLOBAL SAFE WATER 2007. SWASH+ Rapid Assessment Report. Atlanta: Emory University and CARE USA.

THIONG'O, F. W., LUOBA, A. & OUMA, J. H. 2001. Intestinal helminths and schistosomiasis among school children in a rural district in Kenya. *East Afr Med J,* 78, 279-82.

TRAUB, R. J., ROBERTSON, I. D., IRWIN, P., MENCKE, N. & ANDREW THOMPSON, R. C. 2004. The prevalence, intensities and risk factors associated with geohelminth infection in tea-growing communities of Assam, India. *Trop Med Int Health,* 9, 688-701.

UGBOMOIKO, U. S., DALUMO, V., OFOEZIE, I. E. & OBIEZUE, R. N. 2009. Socio-environmental factors and ascariasis infection among school-aged children in Ilobu, Osun State, Nigeria. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 103, 223-8.

UN 2000. United Nations Millennium Declaration. New York: United Nations.

UNICEF 2009. Water, Sanitation and Hygiene Annual Report. New York: UNICEF.

UNICEF 2010. Raising Clean Hands: Advancing Learning, Health, and Participation through WASH in Schools.

UNICEF & INTERNATIONAL WATER AND SANITATION CENTRE (IRC) 2005. Water, Sanitation and Hygiene Education for Schools Roundtable Meeting. Oxford.

UNITED NATIONS 2010. The Millennium Development Goals Report. New York: UN.

WADDINGTON, H., SNILSTVEIT, B., WHITE, H. & FEWTRELL, L. 2009. Water, Sanitation and Hygiene Interventions to Combat Childhood Diarrhoea in Developing Countries. International Initiative for Impact Evaluation (3ie).

WAGNER, E. G. & LANOIX, J. N. 1958. Excreta disposal for rural areas and small communities. *Monogr Ser World Health Organ,* 39, 1-182.

WATKINS, W. E., CRUZ, J. & POLLITT, E. 1996. The effects of deworming on indicators of school performance in Guatemala. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* 90, 156-161.

WEI, X.-N., SHAO, B.-C., FANG, Z.-H., GAO, M. & ZHU, X.-L. 1998. Evaluation of the effects of prevention of diarrhoea and ascaris among students of health intervention measures in schools in rural areas. *China Journal of Public Health,* 14, 228.

WHITE, C., SHINDER, F. S., SHINDER, A. L. & DYER, D. L. 2001. Reduction of illness absenteeism in elementary schools using an alcohol-free instant hand sanitizer. *Journal of School Nursing,* 17, 258-65.

WHITE, G., BRADLEY, D. & WHITE, A. 1972. *Drawers of Water: Domestic Water Use in East Africa.,* Chicago, The University of Chicago Press.

WHO 1995. WHO Model Prescribing Information: Drugs Used in Parasitic Diseases. 2nd ed. Geneva: World Health Organization.

WHO 1999. Improving health through schools national and international strategies. *WHO information series on school health.* World Health Organization.

WHO 2002. World health report: annex table 2: deaths by cause, sex, and mortality stratum in WHO regions and annex table 3: burden of disease in DALYs by cause, sex and mortality stratum in WHO regions. Geneva: World Health Organization.

WHO 2004. Prevention and control of schistosomiasis and soil transmitted helminthiasis. Geneva: World Health Organization.

WHO & UNICEF 2010. Progress on Sanitation and Drinking-water: 2010 Update. *WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.* Geneva.

WHO, UNICEF & UNU 2001. Iron deficiency anaemia: assessment, prevention, and control. A guide for programme managers. Geneva: World Health Organization.

WORDEMANN, M., POLMAN, K., MENOCAL HEREDIA, L. T., DIAZ, R. J., MADURGA, A. M., NUNEZ FERNANDEZ, F. A., CORDOVI PRADO, R. A., ESPINOSA, A. R., DURAN, L. P., GORBEA, M. B., RIVERO, L. R. & GRYSEELS, B. 2006. Prevalence and risk factors of intestinal parasites in Cuban children. *Trop Med Int Health,* 11, 1813-20.

WORLD BANK. 2011. *Primary school enrollment* [Online]. Available: http://data.worldbank.org/indicator/ [Accessed May 16th, 2011.

WORLD BANK & WHO 2003. School Deworming: at a glance. World Bank and World Health Organization.

WORLD HEALTH ORGANISATION 2009a. Global Health Risks: Mortality and burden of disease attributable to selected major risks. Geneva: WHO.

WORLD HEALTH ORGANISATION 2009b. Water, Sanitation and Hygiene Standards for Schools in Low-cost Settings. *In:* JOHN ADAMS, JAMIE BARTRAM, YVES CHARTIER & SIMS, J. (eds.). Geneva: WHO.

WORLD HEALTH ORGANISATION & UN WATER 2010. Global annual assessment of sanitation and drinking-water (GLAAS). *In:* WHO (ed.). Geneva: WHO.

WORLD HEALTH ORGANIZATION 2007. Kenya Country Profile. *Environmental Burden of Disease Series.* Geneva: WHO.

WRIGHT, J., GUNDRY, S. & CONROY, R. 2004. Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Trop Med Int Health,* 9**,** 106-17.

YAJIMA, A., JOUQUET, P., DO, T. D., DANG, T. C., TRAN, C. D., ORANGE, D. & MONTRESOR, A. 2009. High latrine coverage is not reducing the prevalence of soil-transmitted helminthiasis in Hoa Binh province, Vietnam. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 103**,** 237-41.

ZAFAR, S. N., LUBY, S. P. & MENDOZA, C. 2010. Recall errors in a weekly survey of diarrhoea in Guatemala: determining the optimal length of recall. *Epidemiol Infect,* 138**,** 264-9.

4. Assessing the impact of a school-based water treatment, hygiene, and sanitation program on pupil absence in Nyanza Province, Kenya: a cluster-randomized trial

Journal: *Tropical Medicine and International Health*

Authorship order: *Matthew C. Freeman, Leslie E. Greene, Robert Dreibelbis, Shadi Saboori, Richard Muga, Babette Brumback, Richard Rheingans*

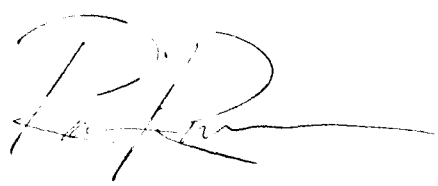
Stage of publication: *Submitted*

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper:

I co-wrote the research proposal and study design, and led field data collection, data cleaning, and executed all analyses. I wrote all drafts of the paper.

Candidate's signature

Supervisor or senior author's signature to confirm role as stated above



4.1 Abstract

There has been increased attention to access to water, sanitation, and hygiene at schools in developing countries, but a dearth of empirical studies on the impact. We conducted a cluster-randomized trial of school-based water treatment, hygiene promotion, and sanitation on pupil absence in Nyanza Province, Kenya, from 2007-2008. Government primary schools nested in three geographic strata were randomly assigned and allocated to one of three study arms (water treatment and hygiene promotion, additional sanitation improvement, or control) to assess the effects on pupil absence at two-years follow-up. Among schools in two of the strata that received water treatment and hygiene promotion there was a 58% reduction in the odds of absence for girls (OR 0.42, CI 0.21-0.85). In the same strata, sanitation improvement in combination with water treatment and hygiene promotion resulted in a comparable drop in absence versus control, though results were marginally significant (OR 0.47, 0.21-1.05). Schools in the third stratum did not show a reduction for either group.

4.2 Introduction

More than 850 million people in the world lack access to an improved water supply and more than 2.5 billion lack access to improved sanitation facilities (WHO and UNICEF, 2010). A target of the UN Millennium Development Goal 7 is to reduce by half the proportion of people without access to water and sanitation by 2015 (UN, 2010). However, improving access to safe drinking water, basic sanitation and hygiene (WASH) at schools (as opposed to

households) is not counted toward the MDG target, perhaps one reason for minimal attention to the low level of WASH coverage in school (UNICEF, 2010). However, another possible reason is that while there is robust evidence of the benefits of household-based improvements in WASH, few studies have addressed the impact of school-level WASH conditions (Clasen et al., 2010, Esrey and Habicht, 1986, Fewtrell and Colford, 2004, Rabie and Curtis, 2006, Curtis and Cairncross, 2003, Clasen et al., 2007). We endeavored to address this evidence gap by assessing the effectiveness of a programmatically delivered WASH intervention in schools.

In this paper, we report on the impact of the intervention on pupil absence; companion papers report on the impact of the intervention on helminth infection (Chapters 5 and 6 of this thesis) and diarrheal disease (Chapter 7). Other outcomes from the assessment will be addressed in other papers but are not part of the research presented in this thesis.

Public domains such as schools can increase the risk of disease transmission (Cairncross et al., 1996, Eisenberg et al., 2007). A substantial proportion of diarrhea cases in school-age children may be acquired in schools rather than homes (Koopman, 1978). Killewo et al. (1991) found clustering of soil-transmitted helminth infections in households where school-age children were infected, indicating children who acquired the illness at school may be agents of transmission to other household members.

School absence has been shown to serve as a proxy for health status among children in developed countries (Houghton, 2003). Absence is associated with

reduced academic performance, school-drop out rates, and general delays in academic and social development, although most data come from middle- and upper-income countries (Lamdin, 1996, Bener et al., 2007, Kearney, 2008, Reid, 2003). In low-income settings, absence might serve as proxy not only for health, but also for socio-economic pressures and societal gender disparity. Improved school water access, sanitation, and hygiene may reduce pupil absence by providing services and a learning environment that appeal to children, specifically girls who are menstruating and lack access to facilities for personal hygiene, and by reducing illness transmission so that children are healthy and able to attend school (Pearson and McPhedran, 2008).

Studies of the effect of WASH improvements in low-income settings have concentrated on household-level WASH; only a small number of school-based studies have been reported. Provision of soap and hygiene education in a Chinese primary school reduced absence by 42% (Bowen et al., 2007). Evaluations of two hygiene and point-of-use water treatment programs in Kenyan primary schools found reductions in absence of 40% and 26%, respectively, though the studies were non-equivalent group designs without experimental controls, did not adjust for clustering, and were conducted in a limited number of schools (Blanton et al., 2010, O'Reilly et al., 2008). An 11% reduction in absence for girls in Bangladesh frequently cited in the literature as evidence of impact for improved sanitation is from a non-experimental design that included monetary subsidies for parents, making this an unreliable figure (UNICEF, 1994). In developed countries, provision of alcohol-based hand sanitizers in school has been shown to reduce absence by 20-51%

(Dyer, 2001, Hammond et al., 2000, White et al., 2001, Guinan et al., 2002, Morton and Schultz, 2004, Sandora et al., 2008). However, a systematic review conducted by Meadows and Le Saux (2004) found that these studies were of low-quality with small sample sizes and improper analysis techniques. A review of sanitation interventions to reduce diarrhoea by Clasen and colleagues found one paper by Wei that reported an 80% reduction in the risk of diarrhea, though the sample size was only 4 schools (Clasen et al., 2010, Wei et al., 1998).

In this study, we assess the impact of an improved school WASH program on absence among primary school children in western Kenya. Additional outcomes and impact measures include access to WASH facilities, knowledge and use of WASH infrastructure, enrollment, and test scores. The Programme, called Sustaining and Scaling School Water, Sanitation, and Hygiene, Plus Community Impact (SWASH+), was funded by the Bill and Melinda Gates Foundation and Global Water Challenge and conducted through a consortium led by CARE USA.

4.3 Methods

4.3.1 Setting

The study area consisted of eight divisions in four districts of Nyanza Province. A rapid assessment conducted in 2007 found that administrative districts further from Kisumu had poorer access to improved water sources in the dry season, greater distance to primary water source, and higher pupil-latrine ratios. For the purposes of this study, contiguous divisions were assigned to three geographic research strata - Nyando/Kisumu East, Rachuonyo, and Suba Districts (Figure 4-1) - in order to represent different variability in climatic and soil conditions, socio-economic status (SES), and school WASH conditions within Nyanza Province. Stratification was employed to ensure that we could capture the differential impact of the intervention on different baseline conditions.

4.3.2 School selection

Research participants were 5,989 pupils in 135 primary schools in Western Kenya. All government primary schools (n=1,084) in these districts received surveys to assess their water and sanitation conditions; surveys were returned by 904 (83%) schools. In order to select schools with poor latrine access, eligible schools were those that failed the Government of Kenya standard for pupil:latrine ratio (25:1 for girls, 30:1 for boys) and reported access to a water source within one kilometer during the dry season (Republic of Kenya Ministry of Education, 2008). Schools that did not meet the latter

criterion were considered "water scarce" and were eligible for a different arm of the trial. These criteria were recommended by implementing partners and Government of Kenya stakeholders and are consistent with internationally recognized school standards (UNICEF, 2004). Of the 198 eligible schools located in the target divisions, 135 were randomly selected and randomly assigned to one of three treatment arms following baseline evaluation:

(1) An intervention package consisting of *hygiene promotion and safe water treatment* provision (HP&WT), including training of teachers on behavior change education, hand washing and drinking water containers, and a one-year supply of WaterGuard (a 1.2% chlorine-based point-of-use water disinfectant locally promoted by Population Services International).

(2) Provision of the aforementioned intervention plus *sanitation*, meaning latrine construction (HP&WT + Sanitation).

(3) A control group to receive all interventions but only at the conclusion of the study (Figure 4-2).

4.3.3 Data collection

We conducted data at baseline (February-March 2007) and following implementation (September-October 2008). Structured interviews were conducted with pupils in the Dholuo language to ascertain absence and WASH knowledge, attitudes, and practices. School absence was measured using pupil-reported incidence in the previous two weeks; we also collected

data from students on the cause and duration of school absence. Previous studies have assessed pupil absence through teacher records, an approach we found problematic. For mative research revealed greater than 95% specificity and sensitivity for two-week absence for students (Freeman, unpublished data).

We based our sample size calculation on the 29% reduction in absence found in previous studies, assuming a baseline rate of 24% and an intra-class correlation of 0.04 (Blanton et al., 2010, O'Reilly et al., 2008). We calculated a minimum sample size of 25 pupils per school and 45 schools per intervention arm using $\alpha=0.05$ $\beta=0.2$. The study includes two cross-sectional data collection times, at baseline and final evaluation. For each round, 25 pupils in each school from grades 4 through 8 (age 9 to 16) were randomly selected from class rosters using systematic sampling (generation of a random number followed by a determined skip pattern). For logistical reasons, 106 schools of the 135 enrolled schools were selected for the baseline study.

Other data were collected via structured interviews in English with head teachers followed by observation of school WASH facilities. In April 2008, we conducted a survey of head teachers and community leaders to assess the effect of post-election violence on migration and destruction of property in our study communities. Enrollment and scores from the Kenya Certificate of Primary Education (KCPE) exams – yearly country-wide exams administered to primary school children in grade eight – were secondary impact measures

and were collected from official records at the school each year. At follow-up, as a secondary measure of absence, we conducted a roll-call assessment of absence for all registered students the day of the field visit.

A systematic sample of households in each school's surrounding community was also selected for data collection. Trained enumerators conducted structured interviews in Dholuo with heads of household having at least one primary school-aged child. Trained enumerators assessed both reported and observed household WASH conditions and behaviors, and demographic characteristics, including a self-reported list of household assets using categories identified in the 1999 Kenya Demographic Health Survey (Houweling et al., 2003, Gwatkin et al., 2000). For the purposes of this analysis, household variables were aggregated for use as community-level (i.e. school) covariates in multivariable analysis.

All data were collected using Syware Visual CE v10 software (Cambridge, MA) on Dell Axim x51 (Round Rock, TX) personal digital assistants (PDAs). Oral consent was obtained from all participants after providing complete details concerning the study. Ethics approval was received from the Institutional Review Board of Emory University (Atlanta, GA), and from the Government of Kenya Ministries of Health, Water, and Education.

4.3.4 Data analysis

Data were cleaned and analyzed in SAS v9.2 (Cary, NC) and STATA v10 (College Station, TX). Latrine quality scores and household wealth scores

were constructed through principal component analysis (PCA) (Filmer and Pritchett, 2001, Vyas and Kumaranayake, 2006). For latrine cleanliness, three observed variables (scaled scores for smell, flies, and dirtiness) were reduced to an index identifying maintenance quality. School latrines without excessive smell, flies, or presence of feces were considered acceptable.

To estimate the impact of the intervention on school absence, we employed multivariable logistic regression models. Standard errors and confidence intervals were adjusted to account for clustering of students within schools and stratification of geographic districts. Probability weights reflected disproportionate sampling of students within schools. The logistic regression models took the form:

$$log\ \frac{\pi_{tij}}{1-\pi_{tij}} = \alpha + \gamma t + G_{1i}\delta_1 + G_{2i}\delta_2 + G_{1i}\theta_1 t + G_{2i}\theta_2 t$$

where (π_{tij}) is the probability of school absence of individual *j* from school *i* at time *t*, G_{1i} indicates assignment to treatment group 1 (HP&WT), and G_{2i} indicates assignment to treatment group 2 (HP&WT + San). We used the same model within each geographic stratum. The parameters θ_1 and θ_2 represent the treatment effects of primary interest, which compare each of group 1 and group 2 versus control. Specifically, we are comparing the logit probability of absence at follow-up in a treatment group with a hypothetical version of what it would have been had the same group been assigned to control. Our hypothetical version assumes that the logit probability of absence would have been the logit probability at baseline in the treatment

group plus the change in the logit probability in the control group from baseline to follow-up. In terms of our regression parameters, θ_1 = A – ((B – C) + D), where A $(\alpha + \gamma + \delta_1 + \theta_1)$ is the logit probability of observed absence at follow-up in treatment group 1 (HP&WT), B $(\alpha + \gamma)$ is the logit probability of absence at follow-up in the control group, C (α) is the logit probability of absence at baseline in the control group, and D $(\alpha + \delta_1)$ is the logit probability of absence at baseline in treatment group 1.

The interpretation is analogous for θ_2, representing the effect in treatment group 2 (HP&WT + San). We reported two treatment effects for each of three geographic strata. We assessed secular trend and tested whether the treatment effects differed across geographic strata.

We included key pupil covariates (grade, gender) together with baseline-level school and community variables determined *a priori* to model fitting. The aggregate variables included school characteristics (pupils per teacher, electricity, cement floors) and community characteristics (proportion of female-headed households, median time to travel to school as a proxy for community size; female head of household education level; proportion of households using a protected water source; proportion of households with a latrine; average latrine condition; and proportion of households in the poorest wealth quintile and the mean asset score). Given the growing sectoral interests in gendered impacts of school programs, we performed a gender-stratified analysis.

We calculated the number of days of pupil absence in the previous two weeks to estimate the number of days of absence avoided per pupil per year by the intervention. We took the double-difference of the aggregate days of absence and multiplied that value by the number of two-week school periods in a school year. Secondary outcome and impact variables – enrollment and test scores – were analyzed by conducting a t-test comparison between intervention and control schools on the school-level change from baseline to final (double difference). P-values were considered significant at the α=0.05 level.

4.5 Results

4.5.1 Baseline school, pupil, and community characteristics

Logistical constraints due to weather prevented baseline visits to 2 of the 135 schools. Data were collected from 2,619 and 3,417 pupils at baseline and follow-up, respectively. Baseline characteristics are presented in Table 4-1. Key factors were similar between intervention and control groups at baseline, with some exceptions, including enrollment, presence of cement flooring, and the percentage of schools who at baseline exceed the Government of Kenya pupil to latrine ratio by three times.

The survey of disruption due to post-election violence revealed "some" or "severe" destruction of property in the Nyando and Kisumu geographic strata (43%), as compared to 4% in Rachuonyo and 7% in Suba ($p<0.001$). There was no statistical difference between intervention packages ($p=.079$). Some

or severe migration occurred in all strata: Nyando/Kisumu (47%), Rachuonyo (24%) and Suba (29%), (p=0.02).

4.5.2 Changes in pupil behavior and knowledge and school conditions

We found significant and substantial differences in key pupil WASH knowledge and practice between intervention and control groups following the intervention (Table 4-2). Pupils' knowledge of key handwashing times (after using the latrine and before eating) and scores on a handwashing demonstration in intervention schools significantly increased from baseline to final evaluation. Intervention schools, even though no extra water supply was provided, significantly improved in consistent provision of drinking water, handwashing water, and soap, as compared to control schools. Schools that received latrines approximately halved their ratios of students per latrine for both girls and boys, but few achieved the Government of Kenya standards.

Though there were significant differences between intervention and control groups at follow-up, a substantial proportion of school improvements did not meet standards necessary to be considered fully compliant. Fewer than 40% of pupils in intervention schools reported that soap was always available; approximately 60% reported that water was always treated; and less than 75% reported drinking water was always available.

4.5.3 Impact analysis: Absence and educational outcomes

There were substantial declines in pupil-reported absence in all geographic strata (Table 4-3); however, in Nyando/Kisumu this resulted in very low levels

of absence such that absence in both intervention and control arms approach zero, making accurate estimation difficult.

Multivariable analyses of the effect of the program on pupil-reported absence overall and stratified by gender, along with interaction terms for geographic strata are reported in Table 4-4. We found no significant impact on absence due to the hygiene promotion and water treatment intervention (OR 0.81, CI 0.50 – 1.35), nor with the addition of sanitation (OR 0.97, CI 0.55 – 1.69) (Table 4). When the analysis was stratified by gender, the impact on girls was suggestive of an effect, but also not found to be significant (OR 0.63, CI 0.31 – 1.27).

We found significant interaction between the Nyando/Kisumu stratum and the other two strata; results from Suba and Rachuonyo were not different from each other. Due to the substantial secular reduction in absence for Kisumu/Nyando and significant effect modification of geographic strata, additional analyses were restricted to only the Suba and Rachuonyo strata.

Table 5 shows subsequent analysis including only effects estimated in the Rachuonyo and Suba geographic strata. The unadjusted results reveal that schools which received water treatment and hygiene promotion had a 39% reduction in pupil absence (Odds Ratio [OR] 0.61, 95% confidence interval [CI] 0.37 – 1.00), while those who received an additional sanitation component in conjunction with hygiene promotion and water treatment showed a reduction of 27% (OR 0.73, 95% CI 0.42 – 1.28) compared to controls. When modeled with covariates, estimates were comparable (Table

4-5, Model 2). There was no significant difference between the effect of the two intervention arms that received water treatment and hygiene promotion with or without sanitation overall (data not shown).

Stratified analysis by gender suggests that the impact of the hygiene promotion and water treatment intervention (with and without the addition of sanitation) is more effective in reducing absence among girls than among boys (Table 4-5, Model 3). Among girls, hygiene promotion and water treatment alone revealed a 58% reduction in the odds of two-week absence (OR 0.42, 95% CI 0.21 – 0.85), but no effect for boys (OR 0.88, 0.45 – 1.71, data not shown). Schools that received HP&WT in addition to sanitation showed comparable results, girls (OR 0.47, 0.21 – 1.05) and not boys (OR 0.98, 95% CI 0.52 – 1.87). Analysis of reported absence due to illness showed similar effects for girls (HP&WT: OR 0.47, 95% CI 0.19 – 1.17; HP&WT+San: OR 0.46, 95% CI 0.18 – 1.17), though less significant estimates. There was no significant difference between the intervention arms (HP&WT vs. HP&WT&San).

The difference in difference for the number of days of absence avoided for girls was 0.34 days per pupil per two-week recall period for HP&WT and 0.38 for HP&WT and sanitation (Table 4-6). We estimate that our intervention could reduce absence among girls by 6.1 days per girl per year for HP&WT and 6.8 days for HP&WT and sanitation.

We found no evidence that our intervention had a significant impact on secondary impact measures: test scores and enrollment (Table 4-5 and Table 4-6).

4.6 Discussion

To our knowledge, this is the first cluster-randomized trial to assess a suite of school-based WASH interventions to detect differences in attendance in low-income settings. Our study found that interventions to improve water quality, hygiene behaviors, and sanitation in schools reduced absence among primary school pupils in the two geographic strata in rural Kenyan that were less impacted by political upheaval. This reduction in absence was in addition to any reduction in absence gained from deworming – an approach shown to reduce absence by 25% among highly infected populations in Kenya – that was done for all children in both the intervention and control arms following each round of data collection (Miguel and Kremer, 2004). As an effectiveness trial of a real programmatic intervention, we believe that these findings provide evidence that hygiene, water treatment, and sanitation interventions can have a substantial impact on absence among girls (Habicht et al., 1999). The magnitude of our results is consistent with, though higher than, other studies of school WASH interventions (Blanton et al., 2010, Bowen et al., 2007, O'Reilly et al., 2008).

One of the strongest findings is that the impact of water quality, hygiene, and sanitation interventions is substantially greater among girls. Poor school WASH conditions are often seen as disproportionately affecting girls, though

few, if any studies have quantified this evidence (UNICEF, 2010). Our results suggest that WASH interventions can be effective in reducing this disparity. However, the results do not clearly identify the mechanism by which girls benefit more, including factors that reduce causes of absence and factors that encourage attendance. Potential explanations for the increased benefit for girls may include greater reductions in exposure to fecal contamination and improved health; the role of improved toilets as an essential part of menstrual management, safety, and privacy; and the role of hand washing water and soap to enable general cleanliness that more directly impacts girls. Conversely, boys may not have been impacted because the key reasons for their absence - helping out with farm work and income generation – was not mitigated by improved WASH access.

The effect of the intervention was limited to the geographic strata where absenteeism was not separately impacted by social upheaval. Sectarian violence following the post-election crisis of 2007 in Kenya most severely impacted communities in this area, which is close to the urban center of Kisumu City and has a higher degree of tribal heterogeneity. As discussed, our survey found higher levels of migration and property destruction around Kisumu City. There were widespread reports of killing, destruction of property, and looting in and around the city and nearby commercial farmland, resulting in considerable out-migration (Gettlemen, 2008). There is the potential that more marginalized populations left the area. Schools were also closed for the first four months of the school year and the schedule for the remainder of the term was altered; our program was shut down at that time as

well. Those families who remained may have been more likely to send their children to school preceding exam time, when final data were collected.

That we did not see an impact on test scores or enrollment is not surprising. Tests vary considerably year to year, as does the capacity of pupils sitting for that test, even within the same school. A more precise estimate may have been obtained had we used a study-administered cognition test. Numerous factors – most notably geography and poverty – may play a role in whether and where parents send their children to school. Given the advent of free primary education in Kenya, it is unlikely that a program that only improves sanitation and hygiene will overcome poverty or other barriers to enrollment, such as poverty, among children that are not currently attending school.

The intervention was effective in improving availability of drinking and handwashing water, soap, and cleanliness of latrines. However, the program was unable to reach the standard of complete access to all of these factors together in many schools; and there was considerable heterogeneity in the effect of the intervention from school to school. Indeed the school-level variance between intervention and control communities increased by 66% from baseline to final. This is potentially due to differential uptake of the intervention from a variety of pre-existing, unmeasured confounders, such as level of community engagement, school leadership, and success of the program delivery. Poor maintenance of new latrines may have rendered them unusable at some schools. Based on our measure of "acceptable latrines" (those without excess smell and flies smell, visible feces), schools that

received sanitation improvement only reached a ratio of 55 pupils per acceptable latrine, well under the Government of Kenya standards. Similarly, some teachers may not have been sufficiently motivated or had time to engage in hygiene promotion or to ensure that handwashing water, drinking water, or soap were available daily. Water was not always available at school, and on average only 40% of pupils in intervention schools said soap was always available.

The effects of single versus multiple WASH interventions is debated in the literature (Esrey and Habicht, 1986, Fewtrell and Colford, 2004). Our data revealed no significant differences between those schools that received water treatment and hygiene promotion and those that received an additional latrine intervention. A conclusion that sanitation has no additive effect over a hygiene promotion and water treatment intervention should be interpreted with caution. While our findings are consistent with the results, in meta-analyses from Esrey (1996) and Fewtrell & Colford (2004), of no added benefit from multiple interventions that improve WASH conditions, there are alternative explanations. One potential explanation is that the sanitation intervention may not have been sufficient in number or quality. Only 29% of schools met the recommended latrine to pupil ratio of 1:25 for girls or 1:30 for boys. Among sanitation schools, the mean ratio of acceptable latrines to pupils was less than 1:50. The benefit of sanitation as an amenity that encourages girls to attend may also depend on the cleanliness of the facility. Another explanation is that the pathogen exposure reduction benefits of sanitation may be conditional upon having adequate hygiene. Intervention compliance at schools

was poor: of the schools receiving improved sanitation only 44% had hand washing water and soap observed at follow up. In addition, none of the schools reported having adequate resources to supply tissue or water for anal cleansing. The mechanisms whereby compliance determines treatment effect deserve further exploration. They suggest a need for programmatic and policy emphasis on ensuring availability of soap and cleanliness of latrines, rather than just supplying infrastructure. Rather than draw conclusions about the additive effects of sanitation on a water treatment and hygiene promotion program, our data suggest that hygiene education may be critical for achieving impact, both independently and in concert with hardware interventions.

4.6.1 Limitations

There are a number of key limitations to this study that impact internal and external validity. In terms of internal validity, the study also presents certain methodological limitations. The precipitous drop in absence between baseline and follow-up in one geographic stratum required us to use a stratified analysis that limited the power of the study to detect differences between intervention and control groups overall. Another limitation is with using recall data. It is likely that in instances where there was not sufficient trust on the part of the respondent, we may be underestimating school absence. Roll-call has been used in previous studies to reduce recall bias (Miguel and Kremer, 2004). However, we only used this method during final data collection. We consider roll-call measures to have limited applicability in this study, since

there is no baseline and pupils are included that may be officially registered but who never attend school, a condition not likely to be remedied by improved WASH access alone.

The study also presents limitations that may impact external validity. Chief among these was the considerable disruption to implementation from the post-election violence following the December 2007 Kenyan presidential election. Considerable displacement of people and loss of property, especially in Kisumu and Nyando Districts, may explain inconsistent results from that geographic area.

A second key limitation of this analysis is the heterogeneity of implementation. Behavior change training and construction of WASH facilities are heavily dependent on local participation and the capacity of local staff, so that some schools received higher quality interventions than others. Additionally, there were several factors that confounded the relationship between intervention and the reduction in absence, including the leadership of the school management committees and head teacher, distance to markets, roads, and environmental conditions.

It is also significant that the intervention called for yearly deworming of all students, an intervention proven to improve school attendance (Miguel and Kremer, 2004). In our case, this reduction may have contributed to a reduction in effect size, since deworming would have reduced absence among students in both intervention and control schools. Helminth infection is highly heterogeneous and clustered, and schools with higher baseline helminths

levels may have benefitted more from deworming and shown greater reductions in absence (Brooker, 2010). Though we can't say for certain, we expect that deworming in both the intervention and control schools would bias our results to the null. The effect of the deworming can not be known, since our baseline levels of infection were lower and the rates of reduction for absence higher than those reported by Miguel and colleagues (Freeman et al., 2011a).

Follow-up data were collected at a time when pupils may have been more likely to attend for test preparation; data could therefore underestimate the potential impact of the intervention at other times. Our study should be considered to be an effectiveness trial at a certain point in time and place that can help formulate policy and research questions for future work, rather than an efficacy trial with definitive findings applicable to all settings.

4.6.2 Conclusion

We found compelling evidence of the impact of school-based WASH improvement on school absence for girls. Though often discussed in the literature, the gender-equity dimension of school WASH intervention has never been appropriately quantified in the literature. Additional work is necessary to fully explain the mechanism of impact on girls: is it privacy, menstrual hygiene management, health, or something else entirely? Future analyses will explore how heterogeneity in absence reduction can be explained by aspects of the school and community, such as water availability, proximity to market, or minimal level of project compliance.

Substantial funding for WASH is focused on household provision of services for achievement of the Millennium Development Goals. However, our study points to the educational and health benefits of providing cost-effective WASH facilities in schools, and the explicit need to ensure high quality hygiene promotion and behavior change approaches. The differential impact seen among girls highlights the need to consider the question of *who* benefits from WASH programming rather than simply *how many*, as is the case with MDG-based targets (Rheingans et al., 2006).

4.6 Tables and Figures

Figure 4-1: Map of intervention area and school locations

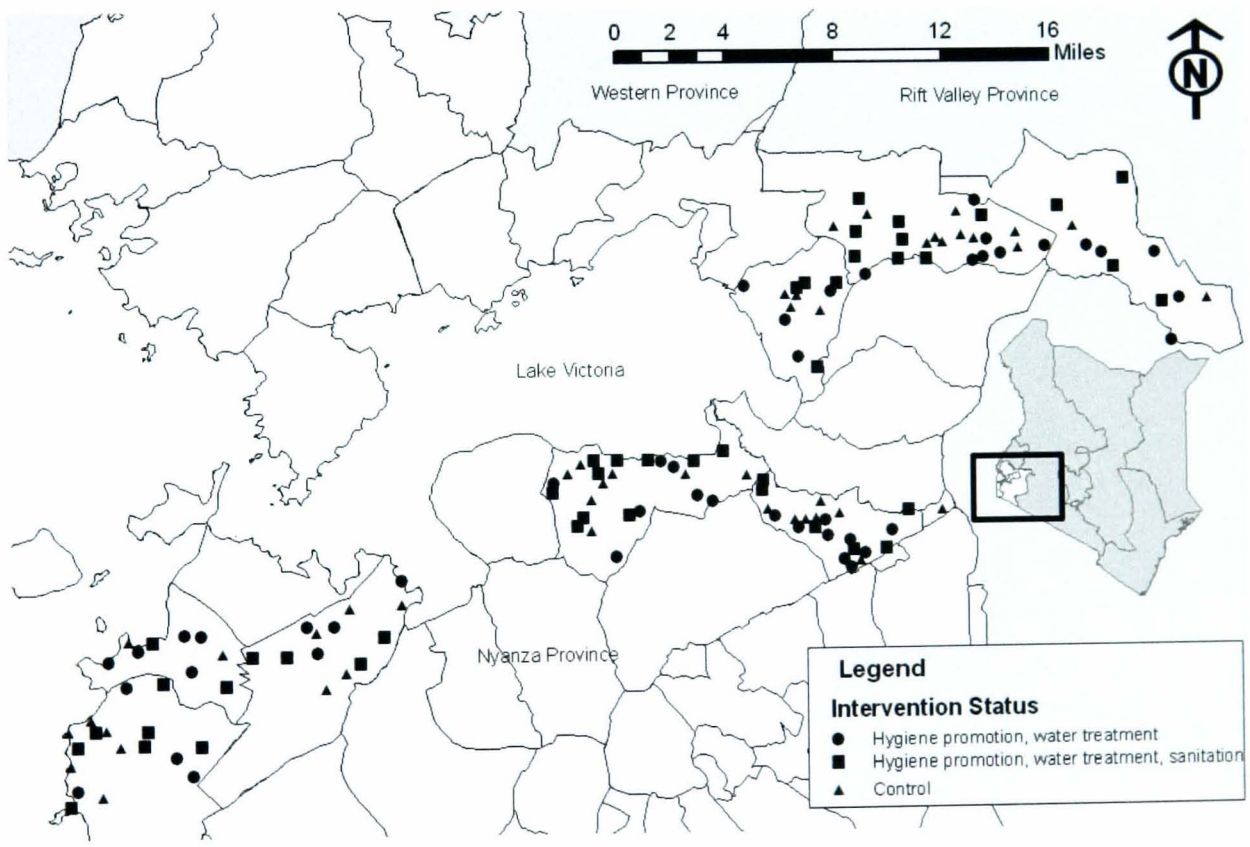


Figure 4-2: School and pupil selection

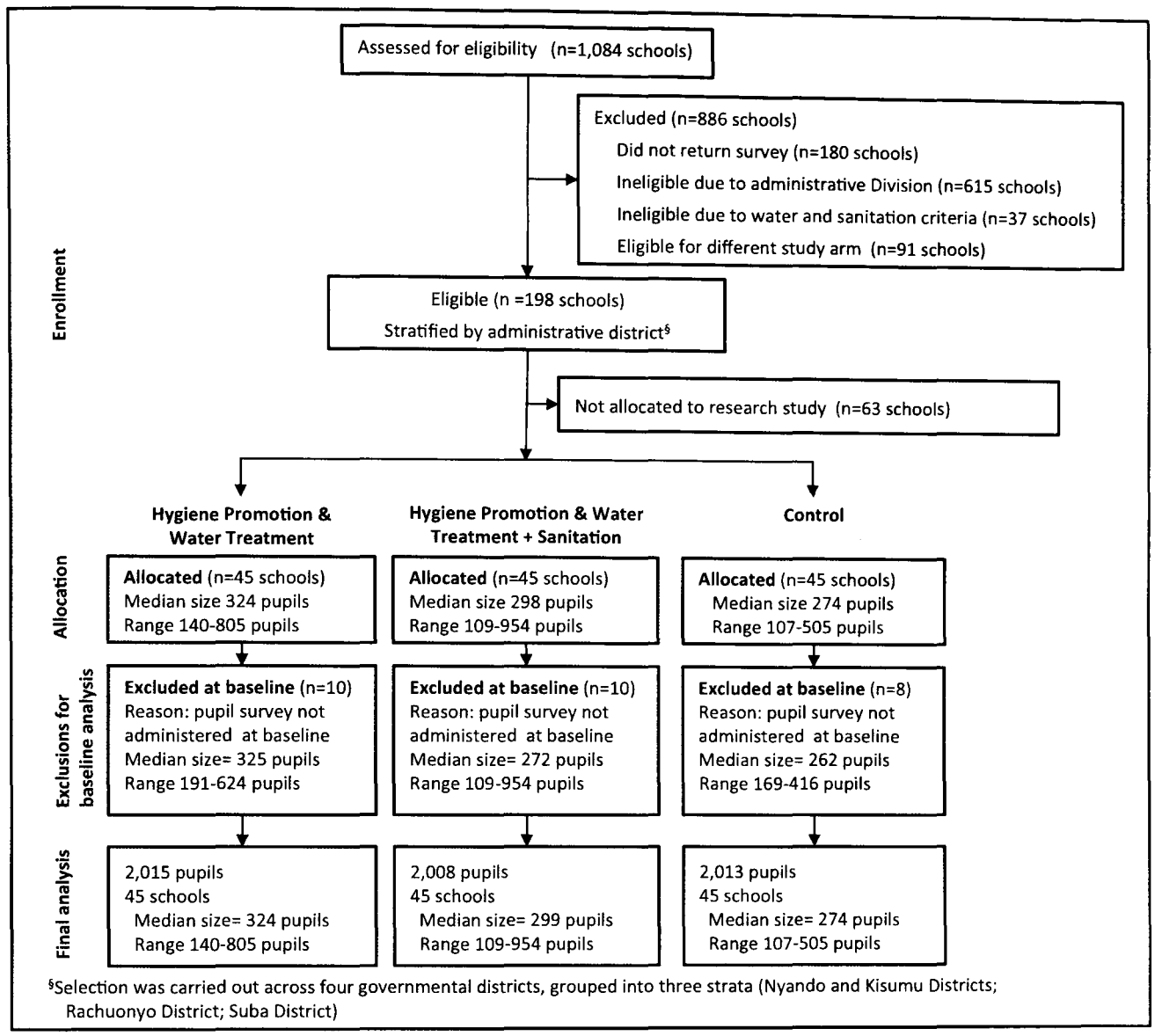


Figure 4-3: Pupil enrollment by intervention arm at three time points

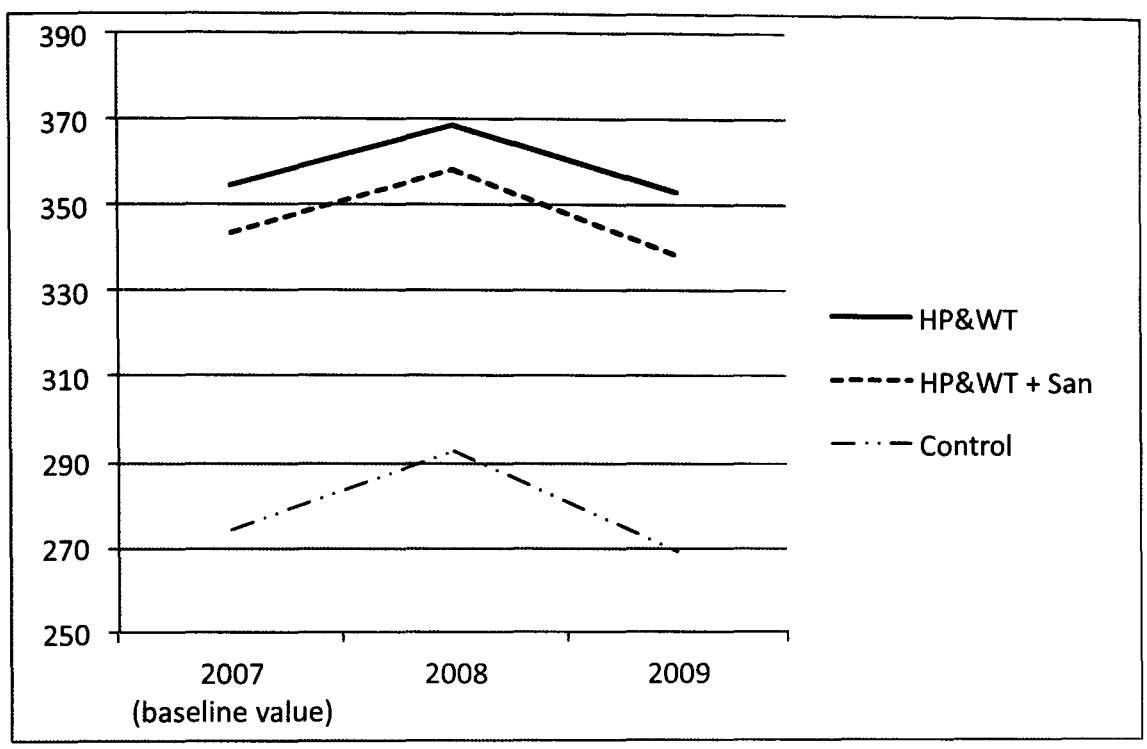


Figure 4-4: Kenya Certificate of Primary Education test results by intervention arm

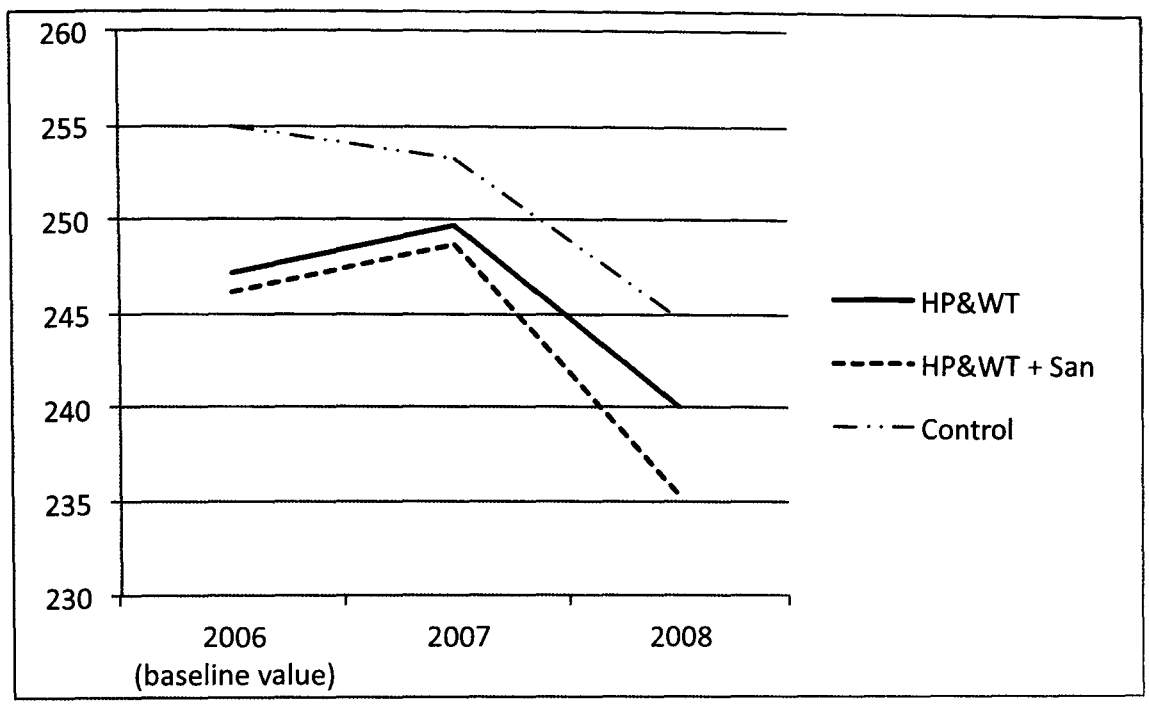


Table 4-1: Comparison of aggregate school, pupil, and household characteristics at baseline between schools in intervention and control arms

Variable	HP&WT	HP&WT + sanitation	Control
Pupil demographics [§]	*n=35*	*n=36*	*n=36*
Age	13.3 (0.4)	13.2 (0.6)	13.4 (0.7)
Grade	5.5 (0.3)	5.9 (0.3)	6.0 (0.5)
Report having a latrine at home	67 (25)	72 (22)	64 (30)
School conditions	*n=45*	*n=44*	*n=44*
Pupils per teacher	33 (10)	33 (12)	28 (7)
Proportion of girls enrolled	48 (3)	48(4)	48(4)
Electricity at school	2 (4%)	2 (4%)	0 (0%)
Iron sheet roofing throughout school	45 (100%)	43 (98%)	43 (98%)
Cement floor throughout school	13 (29%)	10 (22%)	5 (11%)
School current water source is improved[†]	20 (45%)	13 (30%)	18 (41%)
Distance to school current water source in meters	148 (330)	184 (489)	117 (215)
School dry season water source is improved[†]	11 (24%)	13 (30%)	16 (36%)
Distance to school dry season water source in meters	1191 (1322)	865 (964)	1015 (1307)
Pupils per latrine	61 (30)	77 (61)	61 (44)
Boys per latrine	67 (36)	82 (58)	57 (38)
Girls per latrine	60 (32)	78 (68)	57 (40)
Pupil:latrine ratio greater than 3 times government standard			
Boys:latrine > 90:1	12 (27%)	13 (29%)	5 (11%)
Girls:latrine > 75:1	12 (27%)	12 (27%)	7 (16%)
Household demographics[§]	*n=45*	*n=45*	*n=45*
Female-headed households	30 (17)	33 (17)	29 (16)
Female head of household completed primary school	48 (18)	46 (18)	46 (16)
Distance to school from home in minutes	19 (9)	18 (6)	18 (6)
Household respondent used soap during handwashing demo	72 (15)	70 (19)	68 (20)
Household currently using protected drinking water source[†]	64 (31)	64 (30)	66 (32)
Household currently using improved drinking water source[†]	62 (30)	62 (29)	65 (32)
Latrine coverage in community[#]	38 (22)	39 (23)	38 (21)
Percent households in poorest wealth quintile	19 (13)	23 (15)	23 (14)
Percent households in least poor wealth quintile	22 (15)	17 (18)	15 (11)

Data are means (SD) or numbers (%). [§]Mean and (standard deviation) calculated from cluster-level means or proportions. [†]Improved sources include boreholes, rainwater harvesting tanks, protected springs, and protected wells. [#]Improved latrine coverage are latrines within compound or home (WHO, 2010).

Table 4-2: Comparison of pupil and school WASH characteristics among schools that received hygiene promotion (HP), water treatment (WT), sanitation and controls at baseline and follow-up

Variable	HP&WT			HP&WT + sanitation			Control	
	Baseline *n=45*	Follow-up *n=45*	*p value°*	Baseline *n=44*	Follow-up *n=44*	*p value°*	Baseline *n=44*	Follow-up *n=44*
Pupil knowledge and practice variables§								
Mention two key handwashing times (before eating, after defecation)	72 (15)	83 (10)	0.09	73 (18)	85 (10)	0.05	75 (14)	78 (12)
Score out of six during handwashing demonstration	3.8 (0.7)	4.5 (0.6)	0.03	3.8 (0.6)	4.6 (0.5)	<0.001	3.8 (0.7)	4.1 (0.5)
Know all correct steps of water treatment	10 (14)	32 (17)	0.67	9 (10)	29 (15)	0.52	7 (9)	32 (19)
School WASH characteristics								
Pupils report drinking water always available	15 (24)	66 (27)	<0.001	19 (23)	74 (22)	<0.001	16 (20)	29 (32)
Pupils report handwashing water always available	16 (24)	68 (26)	<0.001	16 (21)	76 (22)	<0.001	12 (17)	22 (26)
Pupils report soap always available	1 (4)	36 (28)	<0.001	1 (3)	41 (27)	<0.001	2 (10)	2 (7)
Drinking water available day of field visit	24 (53%)	33 (73%)	<0.001	17 (38%)	37 (82%)	<0.001	23 (52%)	8 (18%)
Detectable chlorine residual in drinking water provided to pupils day of field visit	2 (5%)	28 (62%)	<0.001	1 (2%)	30 (67%)	<0.001	0 (0%)	0 (0%)
Soap available day of field visit	0 (0%)	15 (34%)	<0.001	0 (0%)	21 (45%)	<0.001	0 (0%)	0 (0%)
Handwashing water available day of field visit	7 (16%)	32 (71%)	<0.01	1 (2%)	36 (80%)	<0.001	4 (9%)	2 (4%)
Girls per latrine	59 (32)	56 (25)	0.75	77 (67)	40 (25)	<0.001	57 (40)	50 (20)
Boys per latrine	67 (36)	57 (30)	0.43	82 (58)	44 (28)	<0.001	57 (38)	55 (26)
Number of acceptable latrines†	4.6 (2.9)	6.8 (3.6)	0.68	3.8 (3.0)	9.7 (5.1)	<0.001	3.6 (2.7)	5.4 (2.9)

Data are mean (SD) or number (%) of school-level aggregate data. §Aggregated school-level means. ° *p* value of logistic or linear regression coefficiant on the difference between follow-up and baseline compared to controls. †Latrine does not have excess smell, flies or visible faeces

Table 4-3: Pupil-reported absence at baseline and follow-up and roll call data at follow-up by intervention status and geographic strata

Geographic strata	Intervention package	Pupil-reported		Pupil-reported (Girls)		Roll-call
		Baseline n=2,595	Follow-up n=3,394	Baseline n=1,227	Follow-up n=1,640	Follow-up n=106
Nyando/Kisumu	Hygiene promotion & water treatment (HP&WT)	16.3 (1.8)	4.8 (1.1)	14.5 (3.8)	3.7 (1.3)	11.1 (2.8)
	HP&WT + Sanitation	18.3 (3.8)	6.9 (2.0)	15.9 (4.3)	5.9 (2.9)	8.8 (1.4)
	Control	27.0 (4.2)	4.5 (0.8)	27.1 (6.6)	3.7 (1.3)	12.3 (1.2)
Rachuonyo	HP&WT	24.5 (2.4)	17.8 (2.4)	25.9 (3.9)	15.2 (2.2)	12.0 (1.4)
	HP&WT + Sanitation	16.5 (2.8)	15.2 (2.7)	18.0 (4.4)	19.0 (3.4)	9.9 (0.8)
	Control	17.4 (3.0)	22.6 (2.9)	15.1 (4.5)	28.2 (4.8)	13.2 (1.9)
Suba	HP&WT	24.6 (3.4)	14.3 (2.1)	24.8 (4.1)	16.9 (3.3)	12.2 (1.6)
	HP&WT + Sanitation	30.3 (4.3)	21.0 (3.3)	37.9 (7.7)	22.8 (4.1)	15.6 (2.3)
	Control	28.9 (3.4)	23.0 (3.4)	26.6 (4.8)	24.3 (3.8)	16.8 (2.6)
All regions	HP&WT	22.2 (1.6)	12.3 (1.4)	22.1 (2.5)	11.9 (1.6)	11.8 (1.1)
	HP&WT + Sanitation	21.5 (2.5)	13.8 (1.7)	23.3 (3.9)	15.2 (2.3)	11.3 (1.0)
	Control	24.4 (2.3)	16.2 (1.8)	22.8 (3.3)	18.2 (2.6)	14.1 (1.2)

Data are mean % (SE) for pupil absence accounting for survey weights. Roll-call data are % (SE) for aggregated school-level data

Table 4-4: Model of pupil-reported absence for schools that received hygiene promotion (HP), water treatment (WT), and sanitation (San) vs. control schools by geographic strata (n= 5,989)

	Overall			Girls only			Boys only		
Variable	OR	95% CI	*p*	OR	95% CI	p	OR	95% CI	p
Full model									
Treatment effect: All strata - HP&WT# *(Θ_1)*	0.81	0.49 - 1.34		0.63	0.31 - 1.27		1.04	0.59-1.85	
Treatment effect: All strata - HP&WT + Sanitation# *(Θ_2)*	0.97	0.55 - 1.64		0.79	0.37 - 1.62		1.17	0.65-2.08	
Stratified by geography									
Treatment effect: Kisumu/Nyando - HP&WT# *(Θ_1)*	2.05	0.87-4.83	*	2.17	0.47-10.00		1.85	0.63-5.41	
Treatment effect: Kisumu/Nyando - HP&WT + Sanitation# *(Θ_2)*	2.59	0.82-8.12		3.20	0.60-17.00		2.18	0.62-7.69	
Treatment effect: Rachuonyo - HP&WT# *(Θ_1)*	0.48	0.24-0.98	**	0.23	0.09-0.63	***	1.00	0.41-2.44	
Treatment effect: Rachuonyo - HP&WT + Sanitation# *(Θ_2)*	0.65	0.27-1.60		0.48	0.15-1.58		0.86	0.32-2.29	
Treatment effect: Suba - HP&WT# *(Θ_1)*	0.69	0.36-1.32		0.70	0.27-1.81		0.63	0.28-1.40	
Treatment effect: Suba - HP&WT + Sanitation# *(Θ_2)*	0.83	0.47-1.47		0.55	0.25-1.19		1.20	0.63-2.28	
Interaction: HP&WT in Rachuonyo vs. Kisumu/Nyando	0.24	0.08-0.71	**	0.11	0.02-0.67	**	0.54	0.13-2.18	
Interaction: HP&WT + Sanitation in Suba vs. Kisumu/Nyando	0.25	0.06-1.08	*	0.15	0.02-1.17	*	0.39	0.08-1.95	
Interaction: HP&WT in Suba vs. Kisumu/Nyando	0.34	0.12-0.99	**	0.32	0.05-1.96		0.34	0.09-1.30	
Interaction: HP&WT + Sanitation in Suba vs. Kisumu/Nyando	0.32	0.09-1.16	*	0.17	0.03-1.08	*	0.55	0.13-2.27	
Interaction: HP&WT in Rachuonyo vs. Suba	0.70	2.67-1.82		0.33	0.08-1.32		1.58	0.47-5.23	
Interaction: HP&WT + Sanitation in Rachuonyo vs. Suba	0.78	0.27-2.27		0.88	0.21-3.64		0.71	0.22-2.32	

*# Θ_1 and Θ_2 by geographic strata are the terms that indicate the effect of the intervention controlling for secular trend (time). p = *significance at $\alpha<0.1$, **significance at $\alpha<0.05$, ***significance at $\alpha<0.01$*

Table 4-5: Model of pupil-reported absence for schools that received hygiene promotion (HP), water treatment (WT), and sanitation (San) vs. control schools in Rachuonyo and Suba research strata overall and among girls

Variable	Model 1 (n=3880)			Model 2 (n=3605)			Model 3 : Girls (n=1723)		
	OR	95% CI	*p*	OR	95% CI	*p*	OR	95% CI	*p*
Treatment effect: HP&WT vs. control# (Θ_1)	0.61	0.37-1.00	*	0.63	0.37-1.05	*	0.42	0.21-0.85	**
Treatment effect: HP&WT + Sanitation vs. control# (Θ_2)	0.73	0.42-1.28		0.71	0.39-1.28		0.47	0.21-1.05	*
Baseline imbalance: HP&WT vs. control	1.08	0.75-1.54		0.95	0.63-1.42		1.02	0.56-1.88	
Baseline imbalance: HP&WT + Sanitation vs. control	1.00	0.63-1.58		0.90	0.60-1.36		1.14	0.62-2.10	
Secular trend: Final vs. baseline	0.98	0.68-1.40		0.95	0.64-1.39		1.38	0.78-2.44	
Grade				0.72	0.67-0.77		0.71	0.63-0.79	
Gender: girls vs. boys				1.19	0.97-1.44	*			
Pupils per teacher				1.00	0.99-1.01		1.01	0.99-1.02	
School has electricity				1.61	0.97-2.69	*	2.26	1.16-4.39	**
School has cement floors				0.85	0.62-1.15		0.80	0.54-1.18	
Proportion of female headed household				0.83	0.42-1.66		0.64	0.26-1.60	
Median time to school				1.00	0.98-1.02		1.00	0.98-1.02	
Proportion of female head of household completed primary school				0.48	0.18-1.22		0.26	0.07-0.89	**
Proportion of female head of household that used soap at home				0.40	0.17-0.92	**	0.42	0.13-1.40	
Proportion of household with protected water source				0.87	0.58-1.30		1.14	0.67-1.95	
Proportion of household with latrine				0.61	0.30-1.26		0.78	0.31-1.97	
Mean of latrine cleanliness score				0.94	0.79-1.10		0.81	0.64-1.01	*
Proportion of household in poorest SES quintile				0.71	0.16-3.09		0.22	0.03-1.57	
Mean asset score				0.88	0.26-2.94		0.55	0.09-3.23	

#These variables are the key impact terms that indicate the effect of the intervention (Θ_1) = water treatment and hygiene promotion, WT&HP; (Θ_2) = WT&HP + Sanitation), since they show the impact on absence controlling for the effect of the program (intervention vs. control) and the secular trend between data collection rounds (follow-up vs. baseline).

*p = *significance at α<0.1, **significance at α<0.05, ***significance at α<0.01*

Table 4-6: Reported absence among girls at baseline and follow-up and roll call-data at follow-up by intervention status in Rachuonyo and Suba geographic strata

Geographic strata	Intervention package	Pupil - reported absence		Mean number days absent per pupil per two-week period		Roll-call
		Baseline n=820	Follow-up n=1,033	Baseline n=820	Follow-up n=1,033	Follow-up n=30
Rachuonyo & Suba	Hygiene promotion & water treatment (HP&WT)	24.5 (2.0)	16.2 (1.7)	0.54 (0.08)	0.41 (0.06)	12.5 (1.7)
	HP&WT + Sanitation	23.1 (3.1)	17.7 (2.2)	0.65 (0.15)	0.48 (0.07)	10.6 (0.9)
	Control	23.1 (2.6)	22.8 (2.2)	0.51 (0.11)	0.72 (0.10)	13.1 (2.6)

Data are mean % (SD) at the individual level or at school level (for roll-call data)

4.7 References

BENER, A., KAMAL, M. & SHANKS, N. J. 2007. Impact of asthma and air pollution on school attendance of primary school children: are they at increased risk of school absenteeism? *J Asthma,* 44, 249-52.

BLANTON, E., OMBEKI, S., OLUOCH, G., MWAKI, A., WANNEMUEHLER, K. & QUICK, R. 2010. Evaluation of the role of school children in the promotion of point-of-use water treatment and handwashing in schools and households--Nyanza Province, Western Kenya, 2007. *American Journal of Tropical Medicine and Hygiene,* 82, 664-671.

BOWEN, A., MA, H., OU, J., BILLHIMER, W., LONG, T., MINTZ, E., HOEKSTRA, M. & LUBY, S. P. 2007. A cluster-randomized controlled trial evaluating the effect of a handwashing-promotion program in Chinese primary schools. *American Journal of Tropical Medicine & Hygiene,* 76, 1166-1173.

BROOKER, S. 2010. Estimating the global distribution and disease burden of intestinal nematode infections: adding up the numbers--a review. *Int J Parasitol,* 40, 1137-44.

CAIRNCROSS, S., BLUMENTHAL, U., KOLSKY, P., MORAES, L. & TAYEH, A. 1996. The public and domestic domains in the transmission of disease. *Trop Med Int Health,* 1, 27-34.

CLASEN, T., SCHMIDT, W.-P., RABIE, T., ROBERTS, I. & CAIRNCROSS, S. 2007. Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *British Medical Journal,* 334.

CLASEN, T. F., BOSTOEN, K., SCHMIDT, W. P., BOISSON, S., FUNG, I. C., JENKINS, M. W., SCOTT, B., SUGDEN, S. & CAIRNCROSS, S. 2010. Interventions to improve disposal of human excreta for preventing diarrhoea. *Cochrane Database Syst Rev,* 6, CD007180.

CURTIS, V. & CAIRNCROSS, S. 2003. Effect of washing hands with soap on diarrhoea risk in the community: A systematic review. *The Lancet Infectious Diseases,* 3, 275-281.

DYER, D. L. 2001. Does use of an instant hand sanitizer reduce elementary school illness absenteeism? *The Joural of Family Practice,* 50, 64.

EISENBERG, J. N. S., SCOTT, S. C. & PORCO, T. 2007. Integrating Public Health Control Strategies: Balancing Water Sanitation and Hygiene Interventions to Reduce Diarrheal Disease Burden. *American Journal of Public Health,* 97, 846-852.

ESREY, S. A. & HABICHT, J. P. 1986. Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiologic Reviews,* 8, 117-128.

FEWTRELL, L. & COLFORD, J. M. 2004. Water, Sanitation and Hygiene: Interventions and Diarrhoea, A Systematic Review and Meta-analysis. *In:* PREKER, A. S. (ed.) *Health, Nutrition and Population (HNP) Discussion Paper.* Washington, D.C.: The World Bank.

FILMER, D. & PRITCHETT, L. H. 2001. Estimating wealth effects without expenditure data--or tears: an application to educational enrollments in states of India. *Demography,* 38, 115-32.

FREEMAN, M., CLASEN, T., BROOKER, S., AKOKO, D. & RHEINGANS, R. 2011. The impact of a school-based hygiene, water treatment, and sanitation intervention on reinfection with soil transmitted helminths in western Kenya: a cluster-randomized trial. London: London School of Hygiene and Tropical Medicine.

GETTLEMEN, J. 2008. Vengeance Reignites Kenyan City. *New York Times,* January 29, 2008.

GUINAN, M., MCGUCKIN, M. & ALI, Y. 2002. The effect of a comprehensive handwashing program on absenteeism in elementary schools. *American Journal of Infection Control,* 30, 217-20.

GWATKIN, D. R., RUSTEIN, S., JOHNSON, K., PANDE, R. & WAGSTAFF, A. 2000. Socio-Economic Differences in Health, Nutrition, and Population in Kenya. *Country Reports on HNP and Poverty.* Washington, DC: HPN / Poverty Thematic Group of The World Bank.

HABICHT, J. P., VICTORA, C. G. & P., V. J. 1999. Evaluation designs for adequacy, plausibility and probability of public health programme performance and impact. *Int J Epidemiol,* 28, 10-8.

HAMMOND, B., ALI, Y., FENDLER, E., DOLAN, M. & DONOVAN, S. 2000. Effect of hand sanitizer use on elementary school absenteeism. *Am J Infect Control,* 28, 340-6.

HOUGHTON, F. 2003. The use of primary/national school absenteeism as a proxy retrospective child health status measure in an environmental pollution investigation. *Journal of the Royal Institute of Public Health,* 117, 417-423.

HOUWELING, T. A., KUNST, A. E. & MACKENBACH, J. P. 2003. Measuring health inequity among children in developing countries: does the choice of the indicator of economic status matter? *International Journal for Equity in Health,* 2.

KEARNEY, C. A. 2008. An interdisciplinary model of school absenteeism in youth to inform professional practice and public policy. *Educational Psychology Review,* 20, 257-282.

KILLEWO, J. Z., CAIRNCROSS, S., SMET, J. E., MAIKWANO, L. F. & VAN ASTEN, H. 1991. Patterns of hookworm and Ascaris infection in Dar es Salaam. *Acta Trop,* 48, 247-9.

KOOPMAN, J. S. 1978. Diarrhea and school toilet hygiene in Cali, Colombia. *American Journal of Epidemiology,* 107, 412-20.

LAMDIN, D. J. 1996. Evidence of student attendance as an independent variable in education production functions. *Journal of Educational Research,* 89, 155-162.

MEADOWS, E. & SAUX, N. L. 2004. A systematic review of the effectiveness of antimicrobial rinse-free hand sanitizers for prevention of illness-related absenteeism in elementary school children. *BMC Public Health,* 4.

MIGUEL, E. & KREMER, M. 2004. Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities. *Econometrica,* 72.

MORTON, J. L. & SCHULTZ, A. A. 2004. Healthy Hands: Use of alcohol gel as an adjunct to handwashing in elementary school children. *Journal of School Nursing,* 20, 161-7.

O'REILLY, C., FREEMAN, M., RAVANI, M., MIGELE, J., A., M., AYALO, M., S., O., HOEKSTRA, M. R. & E., Q. R. 2008. The impact of a school-based safe water and hygiene programme on knowledge and practices of students and their parents: Nyanza Province, western Kenya, 2006. *Epidemiology & Infection,* 136, 80-91.

PEARSON, J. & MCPHEDRAN, K. 2008. A literature review of the non-health impacts of sanitation. *Waterlines,* 27, 48-61.

RABIE, T. & CURTIS, V. 2006. Handwashing and risk of respiratory infections: a quantitative systematic review. *Trop Med Int Health,* 11, 258-67.

REID, K. 2003. A Strategic Approach to Tackling School Absenteeism and Truancy: The PSCC scheme. *Educational Studies,* 29, 351-371.

REPUBLIC OF KENYA MINISTRY OF EDUCATION 2008. National School Water, Sanitation and Hygiene Promotion Strategy 2008-2015. Nairobi.

RHEINGANS, R. D., DREIBELBIS, R. & FREEMAN, M. C. 2006. Beyond the Millennium Development Goals: Public health challenges in water and sanitation. *Global Public Health,* 1, 31-48.

SANDORA, T. J., SHIH, M.-C. & GOLDMANN, D. A. 2008. Reducing Absenteeism From Gastrointestinal and Respiratory Illness in Elementary School Students: A Randomized, Controlled Trial of an Infection-Control Intervention. *Pediatrics,* 121, e1555–e1562.

UNICEF 1994. Evaluation of the Use and Maintenance of Water Supply and Sanitation System in Primary Schools. Dhaka: UNICEF.

UNICEF 2010. Raising Clean Hands: Advancing Learning, Health, and Participation through WASH in Schools. New York: UNICEF.

UNITED NATIONS 2010. The Millennium Development Goals Report. New York: UN.

VYAS, S. & KUMARANAYAKE, L. 2006. Constructing socio-economic status indices: how to use principal components analysis. *Health Policy Plan,* 21, 459-68.

WEI, X.-N., SHAO, B.-C., FANG, Z.-H., GAO, M. & ZHU, X.-L. 1998. Evaluation of the effects of prevention of diarrhoea and ascaris among students of health intervention measures in schools in rural areas. *China Journal of Public Health,* 14, 228.

WHITE, C., SHINDER, F. S., SHINDER, A. L. & DYER, D. L. 2001. Reduction of illness absenteeism in elementary schools using an alcohol-free instant hand sanitizer. *Journal of School Nursing,* 17, 258-65.

WHO & UNICEF 2010. Progress on Sanitation and Drinking-water: 2010 Update. *WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.* Geneva.

5. The impact of a school-based hygiene, water treatment, and sanitation intervention on reinfection with soil transmitted helminths in western Kenya: a cluster-randomized trial

Journal: *PLoS NTD*

Authorship order: *Matthew C. Freeman, Thomas Clasen, Daniel Akoko, Simon Brooker, Richard Rheingans*

Stage of publication: *Submitted*

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper:

I co-wrote the research proposal and study design, and led field data collection, data cleaning, and executed all analyses. I wrote all drafts of the paper.

Candidate's signature

Supervisor or senior author's signature to confirm role as stated above

5.1 Abstract

We conducted a cluster-randomized trial to assess the impact of a school-based water treatment, hygiene, and sanitation program on reducing infection with soil-transmitted helminths (STH) following a deworming campaign. Forty government primary schools from three administrative districts in Nyanza Province, Kenya were randomly selected and assigned to intervention or control arms. School pupils were followed-up at two time points over two years following a baseline assessment and assessed for prevalence and intensity of STH infection. The impact of the intervention on the prevalence of *A. lumbricoides* was found to be significant for girls (Odds Ratio [OR] 0.49, 95% confidence interval [CI] 0.25-0.98), but not for boys (OR 0.98, 95% CI 0.52-1.88); the effect on intensity of infection followed a similar pattern. There were no significant effects of the intervention on the prevalence and intensity of *T. trichiura* or on the prevalence of hookworm. For the intensity of hookworm infection, stratification by gender revealed a significant impact among boys (IRR 0.21, CI 0.08-0.57) and a trended, though non-significant increase on girls (IRR 2.12, CI 0.86-5.20).

5.2 Introduction

Vast numbers of the world's population are without access to safe water (884 million people) and sanitation (2.6 billion) (WHO and UNICEF, 2010), and it is estimated that poor access to water, sanitation and hygiene (WASH) is responsible for two million deaths annually and 5.7% of the global disease burden (Pruss et al., 2002). The benefits for health of improving WASH in households, including impacts on diarrhea and respiratory infections, are well established (Rabie and Curtis, 2006, Fewtrell and Colford, 2004, Clasen et al., 2010). By contrast, there is surprisingly little evidence on the health impacts of WASH improvements implemented in schools. This is despite the fact that school environments are highly conducive to exposure to and transmission of infectious diseases due to the mixing of individuals from multiple households and the fact that children spend a large part of their day at school. The risk of infection is further enhanced by the paucity of school sanitation facilities relative to number of users and generally poor hygiene standards (Postlethwaite, 1998). The lack of appropriate and hygienic facilities may discourage children from attending school; in particular, girls who are menstruating may rather not go to school than have to deal with such a lack of privacy. Global WASH coverage figures largely ignore school coverage (WHO and UNICEF, 2010), but UNICEF estimated in 2008 that only 46% of schools in their priority countries had water supply and 37% adequate sanitation coverage (UNICEF, 2009b). Improving WASH access in schools may not only confer health impacts for the school children themselves, but the provision of gender-specific facilities may also improve school attendance by girls. Finally,

the establishment of good hygienic practices among school children may translate to improved practices at home (Onyango-Ouma et al., 2005).

Most research on the impact of household access to WASH on children aged under five years has focused on diarrhea. Among school children, the most common faecal-oral pathogens are soil-transmitted helminth (STH) infections (*Ascaris lumbricoides*, *Trichuris trichiura* and the hookworms, *Necator Americanus* and *Ancylostoma duodenale*). Transmission of these pathogens is direct from mature eggs or larval stages in the external environment to the mouth via fingers contaminated from infected soil, or in the case of hookworm, by infective larvae penetrating unprotected skin. In terms of estimating the impact of WASH improvements, STH infections may afford a more direct, sensitive measure of fecal exposure than diarrhea, which has have multiple causes and relies on self-reported measures that are subject to bias.

It is estimated that STH infection infect two 2 billion individuals worldwide (Crompton, 1999, Hotez et al., 2006). Chronic intense infection can adversely affect growth and cognitive development in school children (Brooker and Bundy, 2008). Fortunately much of the morbidity associated with STH infection can be reversed cheaply and safely by periodic chemotherapy, typically using the anthelminthics, albdendazole or mebendazole (Taylor-Robinson et al., 2007, Hall et al., 2001, Gulani et al., 2007, Smith and Brooker, 2010, Sur et al., 2005). Treatment of school-age children can also reduce infection rates among untreated children and community members (Miguel and Kremer, 2004, Bundy et al., 1990). This is because school-aged

children harbor the greatest burden of infection and are major contributors to overall contamination and parasite transmission. Reducing exposure to helminth infection in schools may therefore have the additional benefit of reducing transmission in the wider community.

However, in the absence of control measures aimed at reducing exposure to infective stages, successful treatment of STH infections is followed by re-infection, necessitating repeated treatments. The benefits of such treatment can be greatly sustained by efforts to reduce environmental exposure to infection through improved sanitation and hygiene behaviour (Asaolu and Ofoezie, 2003, Henry, 1988). As part of a household deworming and hygiene program, Gungoren and colleagues found a reduction in rates of reinfection with *A. lumbricoides* compared to no intervention, but no difference compared to treatment only (Gungoren et al., 2007). However, to date, few studies have evaluated the impact of environmental interventions in the so-called "public" domain as a way to reduce reinfection with STH species (Cairncross et al., 1996). In Palestine, schoolchildren receiving health education for 6 months following deworming showed a statistically significant difference in reinfection rates as compared to those that received deworming only, though the study only included two schools (82.9% reduction compared to 71.2%) (Kanoa et al., 2006). In Brazil, a community level sewage and drainage program revealed significant declines in nematode reinfection (Moraes et al., 2004, Barreto et al., 2010). Despite the increased attention to implementing, sustaining, and scaling school WASH programs, no studies to date have assessed the health impact of comprehensively improving school WASH

conditions (Snel, 2004, UNICEF and International Water and Sanitation Centre, 2005). Here we report the results of a cluster-randomized trial in western Kenya that investigated the impact of school-based WASH program in reducing reinfection with STH species following anthelmintic treatment.

5.3 Methods

5.3.1 Background and study design

This was a cluster-randomized trial among primary school pupils conducted in 39 government primary schools in Nyanza Province, western Kenya, 2007 – 2009. The study was nested within a larger trial assessing the impact of improved access to WASH in schools on absenteeism and diarrheal diseases among school pupils and children under 5 in the school catchment area (Chapter 4). The main study outcomes were the prevalence and intensity of soil-transmitted helminth (STH) species: hookworms (*Ancylostoma duodenale* and *Necator americanus*), roundworm (*Ascaris lumbricoides*), and whipworm (*Trichuris trichiura*). These are the most common STH species, causing the majority of the associated disease burden. *A. lumbricoides* and *T. trichiura* cause infection through ingestion of ova on hands or food. Hookworm infection is caused by dermal exposure to feces in the environment where the larvae penetrate the skin. A recent review of worm infection in East Africa reported median levels in Nyanza Province of *A. lumbricoides* (18.5%), *T. trichuria* (11.9%), hookworm (17.6%) (Brooker et al., 2009). At the start of the trial, all children, regardless whether they were infected or not, were provided with treatment with albendazole.

Secondary outcomes included the prevalence of the trematode, *Schistosoma mansoni* and the prevalence of anemia among primary school children. *S. mansoni* infection was considered a secondary outcome as it is only in part related to sanitation and hygiene, rather it is related to contact with fresh water containing infective stages which can penetrate the skin (Hotez et al., 2006). Additionally, in the study, only children found infected with *S. mansoni* at baseline were given praziquantel, unlike the mass deworming conducted for STH infections. Data were generated from stool and capillary blood samples collected during three cross-sectional rounds (baseline and two follow-ups).

5.3.2 Study area

This study took place in eastern and southern portions of Nyanza Province, Kenya (Figure 5-1). The study population consisted of 3,032 pupils attending 39 government primary schools located in two geographical areas that were chosen for diversity of water access, socio-economic conditions, and logistical proximity to a laboratory for fecal sample analysis.

The study area is mainly rural with poor access to roads and electricity. The population in Nyanza is predominantly from the Luo ethnic group, who are mainly subsistence farmers growing corn, millet, groundnuts, and cassava (Olsen et al., 2001). There are two farming seasons from October-December and March-July; however the rains were inconsistent during the years of the study. Inhabitants that live near Lake Victoria rely on fishing for subsistence and income.

5.3.3 School selection

Forty schools enrolled in a larger trial were randomly selected for inclusion in the study (**Figure 5-2**). Schools were eligible for participation only if they did not meet the Government of Kenya pupil-latrine ratio standard of 30:1 for boys and 25:1 for girls and had a water source within 1 km of the school during the dry season per the Government of Kenya standards. Following baseline data collection, we randomly selected 20 intervention and 20 control schools for this study, stratified by research cluster. One school was excluded due to deworming activities following study enrollment, but prior to baseline data collection, and was not included in the analysis.

5.3.4 Intervention

This study was part of a larger cluster-randomized trial designed to assess the effectiveness of a school-based WASH intervention led by CARE, an international non-governmental organization. Schools selected as part of the intervention group received sanitation infrastructure (ventilated improved pit latrines), hygiene promotion, and point-of use water treatment with dilute sodium hypochlorite (Quick et al., 1999) and hygiene. The number of latrines provided at each school was based on enrollment and the pupil:latrine ratio at baseline. Schools received between four and seven latrine doors, though the total number provided was ultimately based on available funds. In most cases, provision was insufficient to reach the Government of Kenya standard. The hygiene promotion and water treatment components included commercially manufactured handwashing and drinking water storage

containers and a one-year supply of water treatment solution (a 1.25% sodium hypochlorite point-of-use water treatment product distributed by Population Services International with brand name WaterGuard). One parent and one teacher at each school were trained on hygiene behavior change, health education, and proper maintenance of sanitation and water storage facilities. Stakeholders at the school, including parents, teachers, and pupils, were expected to assist with latrine construction, maintain latrines, purchase resupply of water treatment products, and provide soap throughout the year. Intervention schools received the hygiene promotion and water treatment hardware between May and June 2007; latrines were constructed between May 2007 and November 2008.

5.3.5 Deworming

Following every data collection survey, all children in study schools (intervention and control) received mass treatment (May 2007, April 2008, February 2009) for STH infections using a single oral dose of albendazole (400mg) administered by a trained Ministry of Health Public Health Nurse. Albendazole is highly efficacious in curing infection with hookworm (cure rate of 78.8%) and *A. lumbricoides* (93.9%), but is less effective against *T. trichiura* (43.6%) (Keiser and Utzinger, 2008). As such, though we assume no infection following deworming, residual infection may still be present, especially among pupils with high infection. Incomplete cure rates would likely bias our results to the null. Control schools received sanitation improvements and hygiene education following the final round of data collection in May 2009.

The intervention was implemented by CARE, Sustainable Aid in Africa, Water.org, and the Kenya Water and Health Organization.

5.3.6 Sample size calculation

Based on previous surveys in the region, we assumed baseline-levels of infection of 42% for *A. lumbricoides*, 55% for *T.* trichiura, and 77% for hookworm (Miguel and Kremer, 2004) We based our power calculation on *A. lumbricoides* reinfection, given the high cure rate of albendazole, that it is a parasite most correlated with poor sanitation and hygiene, and because of its direct fecal-oral transmission (Keiser and Utzinger, 2008, Hotez et al., 2006). For sample size calculation, we assumed a reinfection to previous levels at follow-up and a conservative intra-cluster correlation (ICC) of 0.18; we estimated the need for 20 schools per arm and 25 pupils per school for power to detect a 20% reduction in reinfection rate between intervention and control using α=0.05 and β=0.2. We increased the number to 27 pupils per school at the second follow-up to ensure a sufficient sample. The estimated effect size was smaller than reductions found as part of a public sewerage and drainage intervention in Salvador, Brazil (Moraes et al., 2004).

5.3.7 Pupil selection

Children enrolled in the study were randomly selected, regardless of sex, from school enrollment registers in standard grades 3 – 5. Children were eligible if they were between 7 and 13 years old at the time of selection, were dewormed by the project in the previous year (during follow-up rounds), and

did not have a sibling who was also enrolled. Siblings were excluded in order to maximize power and avoid the need to adjust for intra-household correlation of infection. This age range was selected because it includes children who have the greatest burden of intestinal STH infection (Chan et al., 1994, Crompton, 1999). Registers were numbered to include the total number of children in the eligible classes. Slips of papers containing those numbers were placed in a hat and randomly selected by hand without replacement. All children not meeting these criteria or who refused deworming drugs for religious or other reasons were excluded from the study.

5.3.8 Stool and blood-hemoglobin sampling

Stool samples were collected at three time points: prior to implementation in May 2007; follow-up 1 in April 2008; and follow-up 2 in February 2009. Children were recruited at school and asked to supply a stool sample the day of the site visit. Stools were examined microscopically within one hour of preparation using the Kato-Katz method (Katz et al., 1972, WHO, 1991). Each stool sample was processed on two separate slides and read by different laboratory technicians. The mean of the two readings was calculated and designated as the value for that pupil. To enhance quality control, a third technician read 10% of the daily results. If a divergence was detected, both slides from that pupil were reread (Stothard et al., 2008).

Haemoglobin concentration was estimated to an accuracy of 1 g/L using a portable WBC system (Hemocue Ltd, Cypress, CA). Anaemia was defined as a haemoglobin concentration <12 g/dL for children aged 12-14 years and

<11.5 g/dL for children aged 5-11 years (WHO et al., 2001). Children with anaemia (<10.0 g/dL) were provided letters from a Government of Kenya Public Health Nurse prescribing iron tablets to be provided at the nearest dispensary. When possible, parents were informed of the diagnosis and the need for treatment.

5.3.9 Surveys

At the time of stool sampling, pupils' age, grade, gender, self-reported soil-eating (geophagy) behavior, and observation of shoe wearing was recorded. School-level assessments included indicators of water, sanitation, and hygiene access at schools. The assessment relied on an interview with the school headmaster and observations of latrine conditions, availability of soap, and water for handwashing. Since observations were not possible throughout the school year, we conducted a set of school visits to directly observe the presence of WASH facilities and to interview children about the presence of drinking water, soap, and handwashing water.

As part of the larger trial, data from a random selection of households enrolled in the trial within the school catchment area were used to develop aggregate school and community-level baseline variables. For this data collection, twenty-five households were systematically sampled by walking the entire area of a community using a skip pattern determined by the total number of households. Female household heads were interviewed about their WASH attitudes and practices; observations were collected on latrine conditions and

household assets. Data here were used to assess aggregated community variables.

School surveys, pupil data, and laboratory data were collected on paper surveys. Data were manually double-entered using Microsoft Access 2003. Data were cleaned and analyzed using SAS version 9.2 (Cary, NC) and Stata version 10 (College Station, TX).

5.3.10 Analysis methods

The impact of the intervention was analyzed in terms of the prevalence of infection (proportion of individuals infected) and the intensity of infection (the number of worms harboured by an individual, which is typically indirectly estimated on the basis of quantitative egg counts (Anderson and Schad, 1985)). The latter is measured since the rate of transmission (and hence the rate of exposure) is directly related to the intensity of infection (Anderson and May, 1991). Moreover, the risk of morbidity is strongly related to the the number of worms harboured by an individual, hence studies of the intensity of infection have the greatest public health relevance (Brooker and Bundy, 2008). Finally, the impact of helminth control efforts is best evaluated using measures of intensity, not prevalence. This is because large reductions in parasite transmission (as measured by the basic reproductive number, which defines the average number of eggs produced by one female worm over her reproductive life that themselves survive to reproductive maturity (Anderson and May, 1991)) will induce changes in infection intensity in a proportional manner, whereas identical changes will induce little measurable change in

infection prevalence until transmission drops to very low levels (Brooker et al. 2004).

For baseline worm burden, we calculated a geometric mean of infected individuals sampled. Prevalence was modeled using logistical regression for presence/absence of individual STH species and *S. mansoni*. The effect of intervention on intensity of infection was based on quantitative egg counts, assuming a negative binomial distribution (Anderson and May, 1991). Models using all *a priori* determined covariates were generated for each STH species individually using similar population-based linear regression techniques.

School and community demographics were assessed for imbalances at baseline using means and proportions and medians. Primary and secondary outcomes were assessed for baseline imbalance and at follow-up using student's t-test, χ^2, or log-linear models as appropriate. Point estimates and standard errors were adjusted for study design, including survey weights based on pupil probability of selection and clustering at the school level.

For multivariable models, to test the impact of the intervention over time, we developed a population-level logistic regression model, which took the form:

$$log\frac{\pi_{tij}}{1-\pi_{tij}} = \alpha + G_i\theta + S_j\varphi + G_iS_j\omega + W_i\delta + X_{tij}\beta$$

where π_{tij} is the probability of school absence of individual *j* from school *i* at follow-up, G_i indicates assignment to the treatment group, S_j is the gender of the child, W_i is the baseline level prevalence of STH infection, and X_{tij}

represents the other covariates: age, soil eating, and shoe wearing. To assess if gender modified the effect of the intervention, we used an adjusted F-test with 2 degrees of freedom to determine if $S_j\varphi = G_iS_j\omega = 0$; if significant, separate odds ratios were reported.

For count outcomes of eggs per gram of feces, we used a negative binomial distribution to account for over-dispersion and test the impact of the intervention on population-level intensity of infection (Anderson and Schad, 1985). The log-linear model took the form:

$$log\ (E(Y_{tij}|G_i, S_j, W_i, X_{tij})) = \alpha + G_i\theta + S_j\varphi + G_iS_j\omega + W_i\delta + X_{tij}\beta$$

where $E(Y_{tij})$ is the expected value of *Y* (eggs per gram of feces of individual *j* from school *i* at time *t*, and G_i indicates assignment to the treatment group. W_i is the baseline mean eggs per gram of feces at school-level, while other regressors are similar to those described above.

Due to baseline imbalances and the effect of chemotherapy on the outcome, the use of an approach modeling the interaction of treatment and round was deemed inappropriate. Probability weights reflected disproportionate sampling of pupils within schools and standard errors accounted for school-level clustering.

Household socio-economic status was calculated using principal component analysis (PCA) (Vyas and Kumaranayake, 2006). An asset score was calculated from questions derived from the 2003 Kenya Demographic and

Health Surveys; water and sanitation indicators were removed (Gwatkin et al., 2007). Continuous asset scores were grouped into quintiles.

Blood hemoglobin levels were assessed using population-level linear regression, controlling for age and gender (Hayes et al., 2009). Similarly, we generated logistic regression models for anemia based on the WHO cutoffs discussed above.

5.3.11 Ethics

Ethics approval was obtained from the Institutional Review Board of Emory University in Atlanta, GA; the Ethical Committee of London School of Hygiene and Tropical Medicine, United Kingdom; and the Ethical Review Committee of Great Lakes University of Kisumu, Kenya. Permission for the study was obtained from the Government of Kenya Ministries of Health, Water, and Education.

Informed parental consent was orally obtained prior to collection of stool from pupils. A meeting with parents and school administrators at participating schools was conducted to explain the procedures, benefits of the program, and benefits and risks to participation. Pupils assented to enrollment in the trial prior to providing a stool sample collection.

5.4 Results

5.4.1 Baseline pupil-, school-, and community-level characteristics

Pupil characteristics, as well as cluster-aggregated data for school and community-level variables are found in Table 5-1. A total of 915 (93.8%) of pupils at baseline provided viable stool samples. Pupil variables were similar at baseline between the intervention and control schools. The mean age in each group was 11.2 years old. Over 50% of pupils wore shoes at baseline; under 40% of boys wore shoes. Nearly 50% reported geophagy (soil eating behavior) at home, while 10% reported geophagy at school.

Measured indicators were similar between intervention and control schools for all measured indicators. No schools had electricity, and though nearly all had metal roofing, few were completed with cement floors throughout all classrooms.

At baseline, schools randomly allocated to the intervention arm had higher mean enrollment (353.6 pupils) compared to controls (291.6 pupils). These schools also had a higher ratio of boys per latrine (98.1 per latrine vs. 63.4 per latrine) and girls per latrine (83.3 per latrine vs. 59.1 per latrine). The mean distance to the school's current water source was 317.1 meters as compared to 45.6 meters for control schools. Schools provided water for drinking fewer than three months a year on average. Fewer than 40% of schools had access to an improved water source during the dry season.

Measured community covariates, such as percent of female heads of household, percent of mothers who completed primary school, community latrine coverage, and the proportion of the households in the lowest socio-economic quintile were comparable between the intervention and control communities.

5.4.2 Baseline infection and Hb levels

Overall, 37.7% of children were infected with at least one STH species, with 6.7% of children harbouring at least two STH species (Table 5-2). A number of imbalances in infection levels were observed between study arms. The prevalence of any STH species was higher in the intervention arm (42.3%) compared to the control (33.4%), though infection with two or more STH species did not vary. Calculated ICCs were also lower for *A. lumbricoides* (0.04), *T. trichiura* (0.08), hookworm (0.13), and *S. mansoni* (0.11). Baseline imbalances existed between intervention and control schools for *A. lumbricoides* infection. The prevalence of *A. lumbricoides* was 15.0% among children in the intervention arm and 5.7% among children in the control arm. There were also differences between intensity of *A. lumbricoides* infection (eggs per gram of feces). Only 5.0% of pupils were infected with *T. trichiura*, with prevalence and intensity slightly higher in the intervention schools. Similar small differences between study arms were observed for hookworm and *S. mansoni*. Hookworm was found in the highest prevalence at baseline: 31.2% and 27.3% in the intervention and control schools, respectively. Overall

3.9% of children were anemic, with no significant differences between study arms.

5.4.3 Unadjusted effect of worm infection at follow-up

At the first follow-up, 946 (97.0%) provided viable stool samples, while 1,033 (86.0%) provided stool at the second follow-up. Overall, infection levels were lower at follow-up compared to at baseline for both intervention and control schools (Table 5-2). There was no statistically significant difference in infection at follow-up between pupils attending intervention and control schools. Prevalence of any single worm species was similar in intervention (18.3%) compared to control (19.2%, p=0.81). In terms of individual species, there were no significant differences between prevalence or infection intensity for individual STH species or *S. mansoni* (Table 5-2).

5.4.4 Soil eating and shoe wearing at follow-up

Although soil eating (geophagy) did not vary by study arms at follow-up overall (intervention: 16.8%, control: 21.0%, p=0.16), there was a significant difference between the proportion of girls practicing geophagia compared to the proportion of boys (29.4% vs. 18.5%, p<0.001). Similarly, girls were more likely to wear shoes at follow-up (73.3%) than boys (59.8%, p<0.001).

5.4.5 Multivariable adjusted models of species infection

Analysis of the prevalence and intensity of individual species revealed some interesting differences between species in the impact of the intervention. In

addition, gender was found to be a significant effect modifier for prevalence and intensity of *A. lumbricoides*, and for the intensity of hookworm. For the purpose of consistency, overall and gender-stratified models are presented for all species.

Children attending intervention schools were less likely to be infected with *A. lumbricoides*, compared to those children in control schools (Table 5-3), but this effect differed by gender. The impact of the intervention on the prevalence of *A. lumbricoides* was found to be marginally significant for girls (Odds Ratio [OR] 0.52, 95% confidence interval [CI] 0.25-1.06), but not for boys (OR 1.08, 95% CI 0.55-2.12). Similarly, intensity of *A. lumbricoides* was lower among girls in the intervention schools (incidence risk ratio [IRR] of 0.24 (95% CI 0.08-0.71), but there was no significant difference between intervention groups among boys (IRR 1.04, 95% CI 0.33-3.28). Age, geophagia and shoe wearing were not significant effect modifiers or confounders in any of the models (Table 5-3).

Overall, we did not find significant effects of the intervention on the prevalence of *T. trichiura* (Table 5-4). Soil eating significantly modified the overall effect and boy-specific effect on intensity of infection. Boys that did not practice geophagy showed a significant effect of the intervention (IRR 0.27, 95% CI 0.12-0.61), while boys who did had an inverse effect, though that relationship was marginally significant (IRR 6.41, 95% 0.79-52.33). The intervention was suggestive of an effect in intensity for girls, but the impact was not significant (IRR 0.61, 95% CI 0.20-1.84).

For the intensity of hookworm infection, stratification by gender revealed no effect on girls (IRR 2.04, 95% CI 0.53-7.94), though a significant effect on boys (Table 5-5). Shoe wearing modified the impact of the intervention on boys: those who wore shoes exhibited a greater reduction (IRR 0.11, 95% CI 0.03-0.42) compared to those without shoes (IRR 0.69, 95% CI 0.18-2.64).

There was no significant impact of the intervention on the prevalence (OR 0.52, CI 0.19-1.47) or intensity of *S. mansoni* infection (OR 0.58, CI 0.21-1.67) (Table 5-6). However, when stratified by gender, a statistically significant impact on the intensity of infection for boys emerged (IRR 0.24, CI 0.10-0.58), while there was no effect on girls (IRR 2.20, CI 0.76-6.42).

5.4.6 Hemoglobin levels and anemia

Hemoglobin data were available for 2,882 (3.6%) pupils; data from 105 pupils were not available due to malfunctioning of Hemocue machines in the field. Prevalence of anemia increased from baseline to follow-up 1 and follow-up 2 in both the intervention and control groups (Figure 5-3). Controlling for gender and age, there was no effect of the intervention on overall hemoglobin levels (Risk ratio 1.01, CI 0.74 – 1.38) or the prevalence of anemia (OR 0.85, CI 0.57 – 1.27) (data not shown). No gender-specific effects were observed.

5.5 Discussion

To our knowledge, this is the first cluster-randomized trial to assess the impact of school-based sanitation and hygiene improvements on reinfection with different STH species following mass anthelmintic treatment. Our

findings reveal mixed results for the impact of improved school-based WASH infrastructure on STH infection, with evidence for gender specific effects of the intervention for different STH species. The effect of the intervention also appeared to be greatest for pupils who did not practice unhygienic behavior such as soil-eating or not wearing shoes.

We found considerable reductions in the prevalence and intensity of reinfection with *A. lumbricoides* in the intervention schools compared to the control schools. However, a gender-stratified analysis revealed that these reductions were only significant among girls. This gender-specific effect of the intervention on *A. lumbricoides* infection on girls was consistent with findings from this same trial that the intervention has a considerable impact on absence among girls, but not boys (Freeman et al., 2011b). There is no evidence that girls are biologically more susceptible to STH infection; rather, these results suggest that improving access to WASH reduces the exposure to feces for girls due to behavior. Girls may be less likely to urinate or defecate in the open than boys, thus may disproportionately benefit when latrines are new or clean, or when handwashing water and soap are available.

No previous studies have investigated gender differences in the impact of WASH facilities, but previous cross-sectional and longitudinal studies have previously shown that improved WASH characteristics are associated with lower levels of *A. lumbricoides* infection (Gunawardena et al., 2005, Traub et al., 2004, Stothard et al., 2008, Knopp et al., 2010). The current study found commensurate reductions in the prevalence of *A. lumbricoides* to other

intervention trials of household- and school-based hygiene promotion programs that have shown reduction in *A. lumbricoides* reinfection on primary school age children (Gungoren et al., 2007, Kanoa et al., 2006). In Brazil, Moraes and colleagues found higher reductions in prevalence of infection due to a community sanitation improvement (Moraes et al., 2003).

Due to similar exposure pathways for *A. lumbricoides* and *T. trichiura* we would expect similar findings for both species. In the present study, we found no intervention effect on *T. trichiura*, either overall or by sex. A possible reason for this finding is the known low efficacy of a single dose of albendazole in treating *T. trichiura* (Olsen et al., 2009, Keiser and Utzinger, 2008). There was however some differential effects according to whether children practiced geophagy. For both boys and girls, pupils who did not report geophagy had lower levels of *T. trichiura* reinfection, with a statistically significant benefit for boys. It follows that pupils who eat soil have an increased risk of STH infection, regardless of the WASH conditions at school (Luoba et al., 2005), but that boys who did not practice geophagia are able to benefit from the intervention.

The effect of the intervention on hookworm among boys but not girls was unexpected. Since hookworm is transmitted usually through contact with infected feces through the sole of the foot, legs, and buttocks, our result reflect the finding that boys are more likely than girls to go without shoes. Boys without shoes showed significantly and substantially greater reductions of hookworm infection at follow-up compared to those in controls; boys with

shoes showed no such reduction. Boys may have greater contact with contaminated soil due to urination patterns around the latrine, and provision of new latrines could substantially reduce exposure for boys without shoes. Finally, shoe wearing is likely associated with economic status, a factor not able to be assessed in this analysis.

Since the intervention was not effective in reducing hookworm infection among girls, it is unsurprising that we did not see a commensurate reduction in overall anemia or anemia among girls. The secular increase in anemia over the course of the study may have resulted from seasonal weather patterns and food availability. One such factor is Kenya's 2007-2008 post-election violence and its negative socio-economic impacts such as food insecurity, and inadequate water, sanitation and hygiene situations (UNICEF, 2009a). These factors likely play a larger role in anemia than school WASH conditions or hookworm infection.

Inevitably there are a number of limitations in our study. Although the reductions in *A. lumbricoides* were substantial and significant, we cannot rule out that our findings are a consequence of baseline imbalances and differential rates or patterns of reinfection between study arms. Though we expected that infection would revert to baseline levels in as few as six months (Hlaing et al., 1987, Hall et al., 1992, Elkins et al., 1988), and our follow-up was 10 months following deworming, the rate of reinfection crucially depends on the intensity of parasite transmission (as measured by the basic reproductive number, R_0), the efficacy of treatment and the percentage of the

overall community which was treated as the result of treating school children (Anderson and May, 1991, Hotez et al., 2006), three factors which are unknown. However, multivariate analysis adjusted for baseline levels.

A number of additional limitations are recognized. First, due to high turnover of pupils, we were unable to follow the same individuals throughout the course of the project. Due to laboratory and budgetary constraints, our sample size at baseline would have been too low to ensure an acceptable sample size at follow-up. Thus, our baseline measures are only for aggregate measures at the school. Since individual propensity for reinfection is a considerable risk factor, using school-level aggregate data induces imprecision in the findings (Quinnell, 2003, Pullan et al., 2010). Second, our study was powered with infection rates from a previous study near the study area that were considerably higher than what we found at baseline, which limited our study power (Miguel and Kremer, 2004). Third, there was considerable heterogeneity in delivery and uptake of the intervention. Only 25% of schools in the intervention reached the Government of Kenya standards for pupil:latrine ratios. We observed handwashing water and soap at only 25% of schools at follow-up. On the other hand, this study should be regarded as an effectiveness trial of a real-world intervention. As such, some schools were more successful at improving access to clean latrines and hygiene behaviors of their pupils. Additional analysis on "treated of the treated" is needed to draw further conclusions about the potential impact of the intervention with higher levels of coverage and compliance.

5.5.1 Conclusions

An increasing number of national governments and international organizations are implementing school-based deworming as part of an integrated school health program (Bundy and Guyatt, 1996). Deworming alone cannot eliminate STH infection if schools and communities lack adequate WASH facilities, and the gains from deworming will only be sustained through improved WASH access. However, implementing WASH programs, including school-based programs, is complex, especially as it is difficult to ensure uniform implementation across schools. Furthermore, poor WASH facilities in schools are only one source of exposure to helminth infection, and any effect on improved WASH facilities is likely to be mediated by differences in other, individual or household mediated, routes of exposure (Cairncross et al., 1996). Our findings provide initial support for the benefit of improved WASH in schools when implemented alongside school-based deworming, but show that the effect is not consistent among boys and girls or among sub-groups with different exposure-related patterns of behaviour. The greater impact of WASH improvements on *A. lumbricoides* among girls points to the inequitable access to sanitation and hygiene at schools and how this can be reduced by intervention. The impact of WASH on hookworm among boys points to the need to address open urination – not just open defecation – through construction of low-cost urinals at school. Additional studies assessing the impact of school WASH are warranted to better understand the impact of school-level interventions and how this impact is augmented by other individual- or community-based efforts to reduce exposure. There is a clear

need for an integrated approach to helminth control that includes improved WASH access as a complement to deworming.

5.6 Tables and Figures

Figure 5-1: Schools selected for inclusion in the study of helminth reinfection in Nyanza Province, Kenya

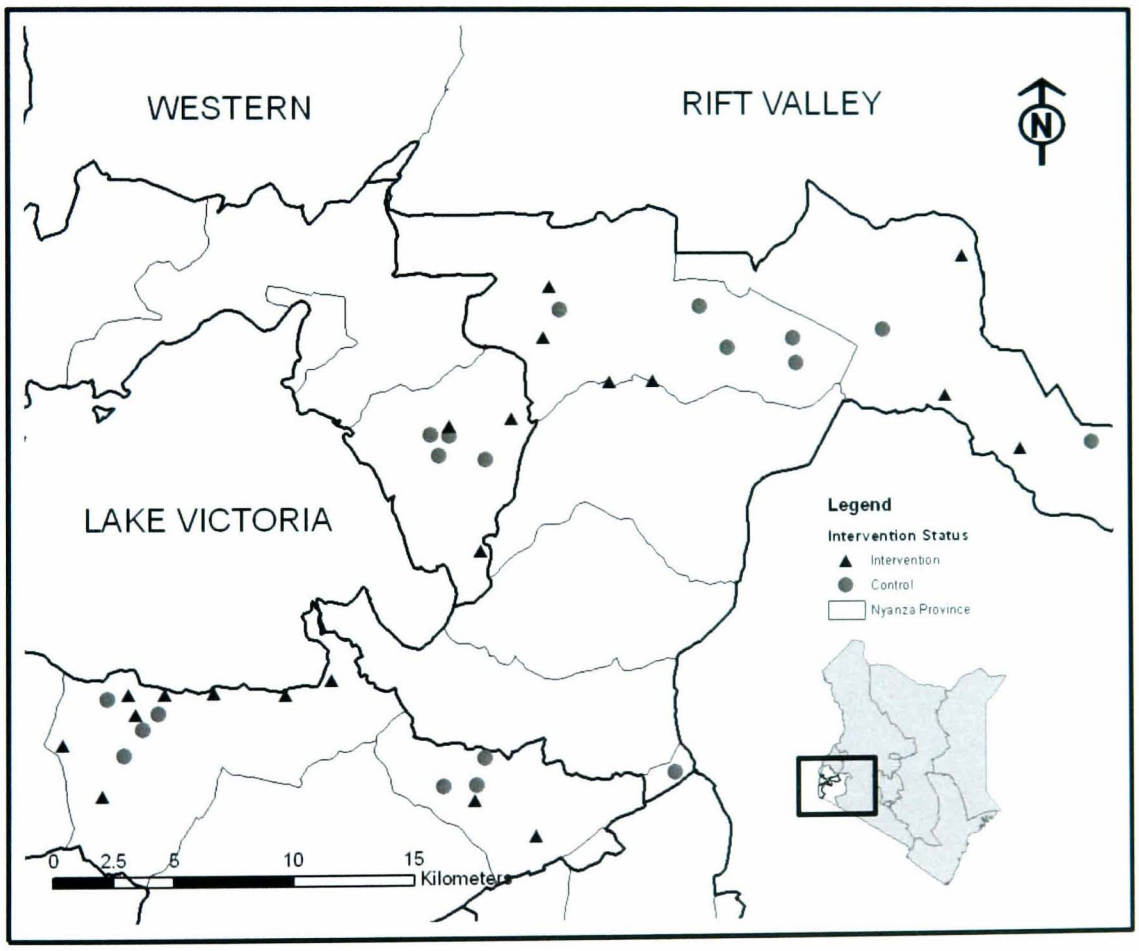
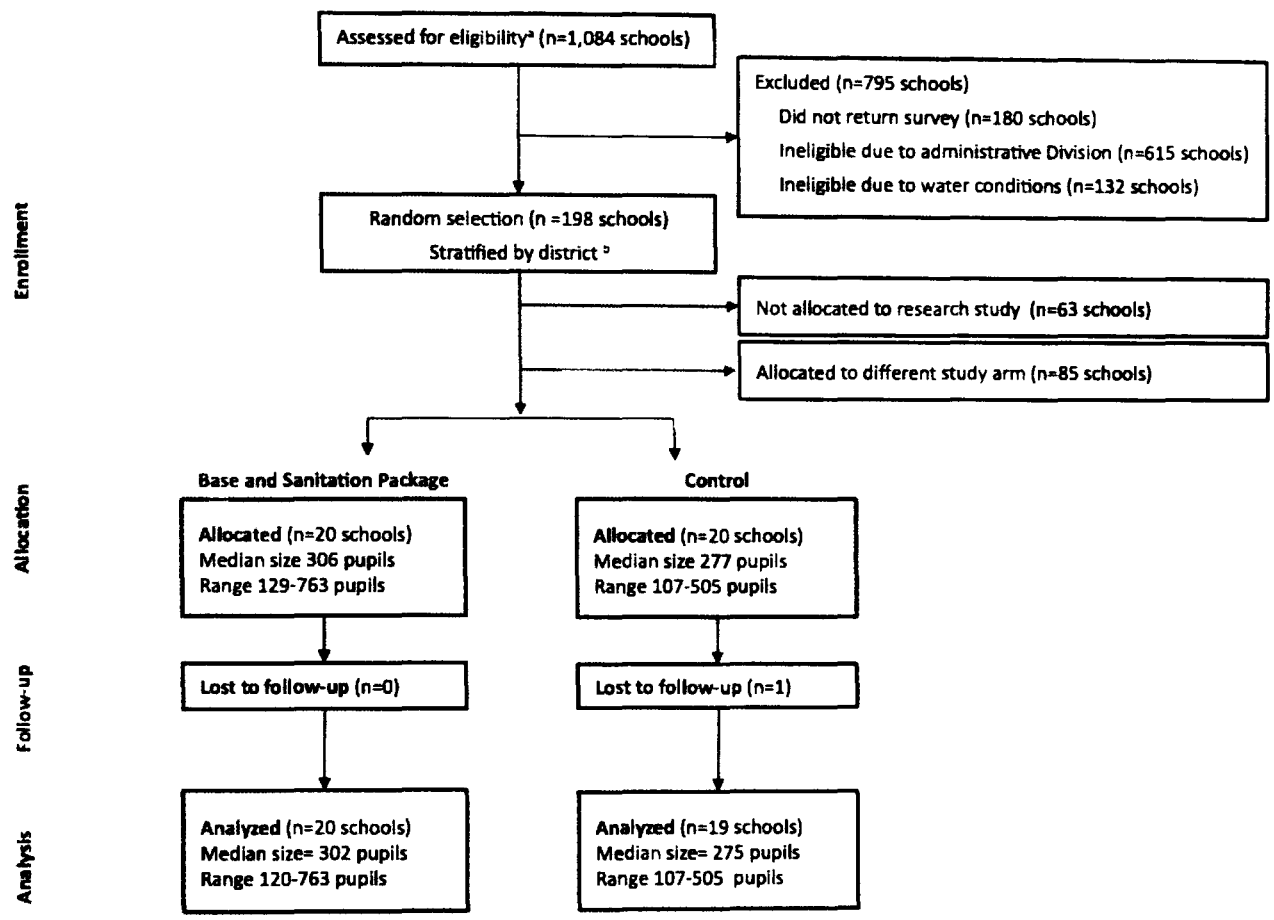


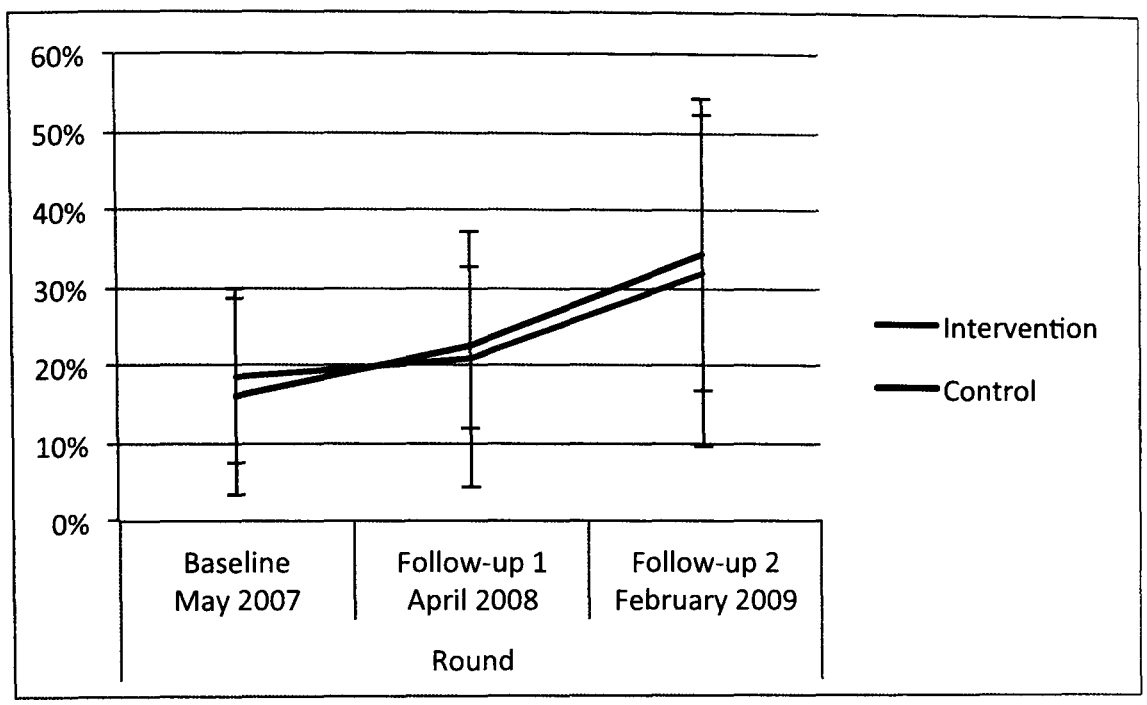
Figure 5-2: School selection flow chart



[a] Schools having no water source within one km and no improved source within two KM were classified as "water scarce" and were excluded from this analysis and are addressed in a separate analysis; Schools with access to a dry season source within one KM who failed to meet the Government of Kenya pupil to latrine ratio (25:1 girls, 30:1 boys) were eligible for the study.

[b] Selection was carried out across three governmental districts, grouped into two strata (Nyando and Kisumu Districts; Rachuonyo District)

Figure 5-3: Rates of anemia among 2,882 pupils in 39 schools from Nyanza Province, Kenya at baseline and two-follow rounds



Anemia based on WHO standards (2001)

Table 5-1: Aggregate school and household characteristics at baseline randomly selected schools and communities in Nyanza Province Kenya. February 2007

Variable	Intervention	Control
Pupil variables[a]	*n=470*	*n=445*
Percent girls sampled	49.4 (10.0)	51.6 (10.4)
Age of respondent	11.2 (0.6)	11.2 (0.6)
Participant wearing shoes	260 (55.4)	231 (52.0)
Participant reports soil eating at school	50 (10.7)	47 (10.6)
Participant reports soil eating at home	229 (48.8)	208 (46.9)
School conditions[a]	*n=20*	*n=19*
No. schools with Electricity at school (%)	0.0 (0.0)	0.0 (0.0)
No. schools with iron sheet roofing throughout school (%)	19 (95)	20 (100)
No. schools with cement floor throughout school (%)	4 (20)	2 (10)
School enrollment in number of pupils	353.6 (162.6)	291.6 (101.7)
Proportion girls	49.8 (2.9)	49.4 (3.8)
Proportion of pupils who are partial orphans	22.1 (9.7)	22.9 (8.2)
Proportion of pupils who are total orphans	12.3 (8.0)	13.1 (6.1)
Pupil:teacher ratio	33.3 (12.1)	29.2 (8.1)
Months water is available throughout year	2.9 (2.6)	2.7 (3.4)
No. schools where dry season water source is protected[b] (%)	7 (35)	8 (40)
No. schools where dry season water source is improved[b] (%)	7 (35)	7 (37)
Mean distance to dry season water source in meters	900.0 (1047.6)	832.1 (1502.8)
Median distance to dry season water source in meters (range)	700 (0-4000)	200 (0-5500)
Pupils per latrine	83.9 (95.0)	61.0 (47.7)
Boys per latrine	91.8 (81.8)	63.4 (41.3)
Girls per latrine	83.3 (85.4)	59.1 (40.2)
Pupil:latrine ratio greater than 3 times government standard		
Number of schools with Boys:latrine ratio > 90:1 (%)	4 (20)	2 (10)
Number of schools with Girls:latrine ratio > 75:1 (%)	1 (5)	2 (10)
Household demographics[b]	*n=20*	*n=19*
Female headed households (mean %)	35.4 (20.0)	27.2 (14.2)
Female head of household completed primary school (mean %)	56.1 (16.9)	52.7 (14.7)
Distance to school from home in minutes (mean of means)	17.8 (4.5)	17.7 (6.8)
Household respondent used soap during handwashing demo (mean %)	78.0 (17.9)	73.3 (17.9)
Household currently using protected drinking water source[b] (mean %)	63.1 (33.1)	66.5 (30.9)
Household currently using improved drinking water source[b] (mean %)	62.0 (33.0)	63.8 (30.1)
Latrine coverage in community (mean %)	49.1 (22.5)	50.9 (22.0)
Perent of households in lowest wealth quintile (mean %)	21.2 (13.4)	15.3 (10.7)
Percent of househlds in least poor wealth quintile (mean %)	19.9 (17.2)	19.6 (12.1)

[a]Point estimate is the mean and (standard deviation) unless otherwise indicated. [b]Protected sources are definited by the UNICEF/WHO joint monitoring programme (JMP.org). Improved sources are proteted sources within 1km of the point-of-use. [b]Household stats are agggregated from household surveys and are presented as mean percentages (and standard deviations of the mean).

Table 5-2: Prevalence of soil transmitted helminth infection and schistosmiasis at baseline and two follow-up rounds by worm type, prevalence of multiple worm infection, and worm burden in eggs per gram (epg)

Prevalence of soil transmitted helminth infection and schistosmiasis at baseline and two follow-up rounds by worm type, prevalence of multiple worm infection, and worm burden in eggs per gram (epg)

	Baseline		Final		
Variable[a]	Intervention (n=20)	Control (n=19)	Intervention (n=20)	Control (n=19)	*p-value*[b]
Multiple STH infection					
% with at least 1 STH infection	42.3 (5.3)	32.9 (4.1)	18.3 (2.8)	19.2 (2.2)	0.81
% with at least 2 STH infection	9.6 (2.4)	4.0 (1.4)	3.3 (0.9)	2.8 (0.8)	0.65
% with at least 3 STH infection	0.8 (0.4)	0.4 (0.3)	0.1 (0.1)	0.4 (0.2)	0.12
Ascaris lumbricoides (roundword)					
Prevalence	15.4 (3.2)	5.6 (2.1)	6.9 (1.5)	6.8 (1.6)	0.98
Geometric mean epg of the infected	1090.2 (186.1)	510.4 (131.1)	425.1 (81.3)	703.2 (111.9)	0.58
Trichuris trichiura (whipworm)					
Prevalence	6.0 (1.3)	5.8 (1.2)	5.6 (1.1)	6.1 (0.9)	0.73
Geometric mean epg of the infected	13.8 (4.9)	7.2 (2.5)	17.2 (5.3)	21.8 (8.4)	0.85
Hookworm					
Prevalence	31.2 (4.0)	27.3 (3.8)	9.2 (1.8)	9.3 (1.9)	0.94
Geometric mean epg of the infected	146.8 (23.5)	103.7 (21.8)	35.5 (6.1)	36.9 (8.2)	0.55
Schistosoma mansoni					
Prevalence	6.4 (2.7)	2.2 (0.9)	6.5 (2.1)	5.0 (1.7)	0.57
Geometric mean epg of the infected	14.0 (5.1)	12.5 (7.8)	23.8 (4.1)	11.9 (3.5)	0.65
Hemogloban levels					
Anemia[b]	3.9 (0.1)	3.9 (0.7)	7.8 (2.0)	8.4 (1.7)	0.94
Mean Hb level	12.7 (0.1)	12.5 (0.2)	12.1 (0.1)	12.1 (0.1)	0.95

[a]*Point estimates are weighted means or proportions as indicated and (standard error) for values. Worm burden is measured by eggs per gram of feces.* [b] *p-values* based on a cluster-level double difference analysis. [c]*<12 g/dL for children aged 12-14 years and <11.5 g/dL for children aged 5-11 years*

Table 5-3: *Ascaris lumbricoides* reinfection among pupils attending schools that received hygiene promotion, sanitation, safe water treatment provision compared to control schools, overall and stratified by gender

Variable	**Overall (n=1964)**			**Girls (n=1030)**			**Boys (n=934)**		
	Estimate	**95% CI**	***p***	**Estimate**	**95% CI**	***p***	**Estimate**	**95% CI**	***p***
Prevalence	**OR**			**OR**			**OR**		
Intervention	0.68	0.42-1.09	0.10	0.52	0.25-1.06	0.07	1.08	0.55-2.12	0.80
Gender	1.50	1.07-2.12	0.01						
Age	1.05	0.91-1.23	0.45	1.05	0.83-1.33	0.67	1.05	0.85-1.30	0.61
Shoes	0.81	0.52-1.28	0.37	0.60	0.32-1.11	0.10	1.31	0.75-2.29	0.32
Pica	1.22	0.77-1.94	0.38	1.12	0.62-2.02	0.68	1.39	0.85-2.28	0.18
Baseline worm level	153.00	43.70-538.0	<0.01	51.70	9.88-270.00	<0.01	65.10	9.63-441.00	<0.01
Intensity of infection	**IRR**			**IRR**			**IRR**		
Intervention	0.35	0.14-0.89	0.02	0.24	0.08-0.71	0.01	1.04	0.33-3.28	0.93
Gender	1.04	0.47-2.33	0.90						
Age	1.11	0.89-1.37	0.33	1.11	0.83-1.48	0.46	1.13	0.85-1.53	0.37
Shoes	0.76	0.36-1.62	0.46	0.53	0.22-1.31	0.16	0.96	0.44-2.12	0.93
Pica	0.99	0.54-1.84	0.99	1.46	0.52-4.14	0.46	1.03	0.38-2.77	0.94
Baseline worm level	1.00	1.00-1.00	<0.01	1.00	1.00-1.00	0.08	1.00	1.00-1.00	<0.01

Models calculated for two follow-up rounds, 8 to 10 months following school-wide deworming

Table 5-4: *Trichuris trichiura* reinfection among pupils attending schools that received hygiene promotion, sanitation, safe water treatment provision compared to control schools, overall and stratified by gender

Variable	Overall (n=1964)			Girls (n=1030)			Boys (n=934)		
	Estimate	95% CI	*p*	Estimate	95% CI	*p*	Estimate	95% CI	*p*
Prevalence	OR			OR			OR		
Intervention	0.94	0.51-1.73	0.84	1.29	0.64-2.63	0.46	0.73	0.39-1.38	0.33
Gender	0.98	0.67-1.44	0.93						
Age	1.02	0.86-1.22	0.80	1.00	0.80-1.26	0.94	1.04	0.80-1.36	0.74
Shoes	0.93	0.66-1.32	0.68	0.91	0.51-1.67	0.77	0.89	0.51-1.55	0.67
Pica	1.83	1.01-3.31	0.04	2.11	0.86-5.20	0.09	1.48	0.82-2.69	0.19
Baseline worm level	59.30	0.34-1,043.0	0.11	32.00	0.94-1,086.00	0.05	4.99	0.13-194.00	0.37
Intensity of infection	IRR			IRR			IRR		
Intervention				0.61	0.20-1.84	0.37			
Intervention: No Pica[§]	0.34	0.14-0.80	0.01				0.27	0.12-0.61	<0.01
Intervention: Pica[§]	2.63	0.67-10.3	0.16				6.41	0.79-52.33	0.08
Gender	1.38	0.65-2.95	0.39						
Age	0.83	0.63-1.11	0.21	0.79	0.55-1.15	0.22	0.82	0.56-1.21	0.31
Shoes	0.46	0.22-0.97	0.04	0.82	0.19-3.67	0.79	0.53	0.20-1.39	0.19
Pica	0.70	0.23-2.19	0.53	1.79	0.72-4.47	0.20	0.91	0.26-3.27	0.89
Baseline worm level	1.04	0.99-1.10	0.13	1.06	0.99-1.15	0.07	1.00	0.99-1.01	0.72

Models calculated for two follow-up rounds, 8 to 10 months following school-wide deworming. § Separate estimates of effect are reported where interaction was found.

Table 5-5: Hookworm reinfection among pupils attending schools that received hygiene promotion, sanitation, safe water treatment provision compared to control schools, overall and stratified by gender

Variable	Overall (n=1964)			Girls (n=1030)			Boys (n=934)		
	Estimate	95% CI	*p*	Estimate	95% CI	*p*	Estimate	95% CI	*p*
Prevalence	OR			OR			OR		
Intervention				1.42	0.68-2.95	0.33			
Intervention: No Shoes[§]	1.07	0.62-1.85	0.78				0.62	0.27-1.46	0.26
Intervention: Shoes[§]	1.32	0.75-2.37	0.36				1.20	0.52-2.81	0.64
Gender	0.81	0.54-1.24	0.34						
Age	1.25	1.10-1.43	<0.01	1.35	1.13-1.61	<0.01	1.20	1.02-1.41	0.02
Shoes	0.47	0.30-0.76	<0.01	0.46	0.30-0.71	<0.01	0.34	0.11-1.07	0.06
Pica	1.75	1.04-2.95	0.03	1.75	0.90-3.40	0.09	1.75	0.83-3.68	0.13
Baseline worm level	10.40	2.49-43.80	<0.01	3.25	0.61-17.40	0.16	6.97	2.24-21.60	<0.01
Intensity of infection	IRR			IRR			IRR		
Intervention				2.04	0.53-7.94	0.28			
Intervention: No Shoes[§]	0.22	0.08-0.60	<0.01				0.11	0.03-0.42	<0.01
Intervention: Shoes[§]	2.04	0.98-4.25	0.06				0.69	0.18-2.64	0.58
Gender	0.63	0.32-1.27	0.19						
Age	1.42	1.17-1.74	<0.01	1.69	1.29-2.21	<0.01	1.11	0.86-1.43	0.39
Shoes	0.12	0.04-0.38	<0.01	0.53	0.21-1.32	0.16	0.12	0.02-0.55	<0.01
Pica	1.18	0.59-2.39	0.62	1.18	0.57-2.45	0.63	1.58	0.72-3.48	0.24
Baseline worm level	1.00	1.00-1.00	<0.01	1.00	1.00-1.00	0.06	1.00	1.00-1.00	0.03

Models calculated for two follow-up rounds, 8 to 10 months following school-wide deworming. § Separate estimates of effect are reported where interaction was found.

Table 5-6: *Schistosoma mansoni* reinfection among pupils attending schools that received hygiene promotion, sanitation, safe water treatment provision compared to control schools, overall and stratified by gender

Variable	Overall (n=1964)			Girls (n=1030)			Boys (n=934)		
	Estimate	95% CI	*p*	Estimate	95% CI	*p*	Estimate	95% CI	*p*
Prevalence	OR			OR			OR		
Intervention	0.52	0.19-1.47	0.21	0.87	0.27-2.84	0.81	0.50	0.22-1.16	0.10
Gender	0.75	0.41-1.38	0.35						
Age	1.15	0.99-1.34	0.05	1.27	1.04-1.56	0.02	1.06	0.84-1.34	0.58
Shoes	1.20	0.73-1.99	0.44	1.08	0.52-2.26	0.82	1.41	0.83-2.40	0.19
Pica	1.20	0.72-2.02	0.47	1.50	0.80-2.81	0.19	0.98	0.47-2.07	0.96
Baseline worm level	4,949.00	388.00-6,299.0	<0.01	4,227.00	3,545.00-5.04	<0.01	132.00	29.70-589.00	<0.01
Intensity of infection	IRR			IRR			IRR		
Intervention	0.58	0.21-1.67	0.31	2.20	0.76-6.42	0.14	0.24	0.10-0.58	<0.01
Gender	0.92	0.43-1.96	0.82						
Age	1.31	1.00-1.71	0.04	1.44	0.91-2.28	0.11	1.10	0.83-1.46	0.47
Shoes	1.47	0.83-2.62	0.17	1.42	0.52-3.87	0.47	1.89	1.12-3.17	0.01
Pica	1.67	0.57-4.91	0.33	3.97	0.79-20.00	0.09	0.86	0.39-1.91	0.71
Baseline worm level	1.04	1.01-1.07	<0.01	1.03	0.99-1.08	0.09	1.04	1.02-1.06	<0.01

Models calculated for two follow-up rounds, 8 to 10 months following school-wide deworming

5.7 References

ANDERSON, R. M. & MAY, R. M. 1991. *Infectious Diseases of Humans,* Oxford, U.K., Oxford University Press.

ANDERSON, R. M. & SCHAD, G. A. 1985. Hookworm burdens and faecal egg counts: an analysis of the biological basis of variation. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 79, 812-25.

ASAOLU, S. O. & OFOEZIE, I. E. 2003. The role of health education and sanitation in the control of helminth infections. *Acta Trop,* 86, 283-94.

BARRETO, M. L., GENSER, B., STRINA, A., TEIXEIRA, M. G., ASSIS, A. M., REGO, R. F., TELES, C. A., PRADO, M. S., MATOS, S., ALCANTARA-NEVES, N. M. & CAIRNCROSS, S. 2010. Impact of a citywide sanitation program in Northeast Brazil on intestinal parasites infection in young children. *Environ Health Perspect,* 118, 1637-42.

BROOKER, S. & BUNDY, D. A. P. 2008. Soil-transmitted helminths (geohelminths). *In:* COOK, G. C., ZUMLA, A.I. (ed.) *Manson's Tropical Diseases.* 22nd ed ed. London: Elsevier.

BROOKER, S., KABATEREINE, N. B., SMITH, J. L., MUPFASONI, D., MWANJE, M. T., NDAYISHIMIYE, O., LWAMBO, N. J., MBOTHA, D., KARANJA, P., MWANDAWIRO, C., MUCHIRI, E., CLEMENTS, A. C., BUNDY, D. A. & SNOW, R. W. 2009. An updated atlas of human helminth infections: the example of East Africa. *Int J Health Geogr,* 8, 42.

BUNDY, D. A. & GUYATT, H. L. 1996. Schools for health: Focus on health, education and the school-age child. *Parasitol Today,* 12, suppl 1-16.

BUNDY, D. A., WONG, M. S., LEWIS, L. L. & HORTON, J. 1990. Control of geohelminths by delivery of targeted chemotherapy through schools. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 84, 115-20.

CAIRNCROSS, S., BLUMENTHAL, U., KOLSKY, P., MORAES, L. & TAYEH, A. 1996. The public and domestic domains in the transmission of disease. *Trop Med Int Health,* 1, 27-34.

CHAN, M. S., MEDLEY, G. F., JAMISON, D. & BUNDY, D. A. 1994. The evaluation of potential global morbidity attributable to intestinal nematode infections. *Parasitology,* 109 (Pt 3), 373-87.

CLASEN, T. F., BOSTOEN, K., SCHMIDT, W. P., BOISSON, S., FUNG, I. C., JENKINS, M. W., SCOTT, B., SUGDEN, S. & CAIRNCROSS, S. 2010. Interventions to improve disposal of human excreta for preventing diarrhoea. *Cochrane Database Syst Rev,* 6, CD007180.

CROMPTON, D. W. 1999. How much human helminthiasis is there in the world? *Journal of Parasitology,* 85, 397-403.

ELKINS, D. B., HASWELL-ELKINS, M. & ANDERSON, R. M. 1988. The importance of host age and sex to patterns of reinfection with Ascaris lumbricoides following mass anthelmintic treatment in a South Indian fishing community. *Parasitology,* 96 (Pt 1), 171-84.

FEWTRELL, L. & COLFORD, J. M. 2004. Water, Sanitation and Hygiene: Interventions and Diarrhoea, A Systematic Review and Meta-analysis. *In:* PREKER, A. S. (ed.) *Health, Nutrition and Population (HNP) Discussion Paper.* Washington, D.C.: The World Bank.

GULANI, A., NAGPAL, J., OSMOND, C. & SACHDEV, H. P. 2007. Effect of administration of intestinal anthelmintic drugs on haemoglobin: systematic review of randomised controlled trials. *BMJ,* 334, 1095.

GUNAWARDENA, G. S., KARUNAWEERA, N. D. & ISMAIL, M. M. 2005. Effects of climatic, socio-economic and behavioural factors on the transmission of hookworm (Necator americanus) on two low-country plantations in Sri Lanka. *Ann Trop Med Parasitol,* 99, 601-9.

GUNGOREN, B., LATIPOV, R., REGALLET, G. & MUSABAEV, E. 2007. Effect of hygiene promotion on the risk of reinfection rate of intestinal parasites in children in rural Uzbekistan. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 101, 564-9.

GWATKIN, D. R., RUSTEIN, S., JOHNSON, K., SULIMAN, E., WAGSTAFF, A. & AMOUZOU, A. 2007. Socio-Economic Differences in Health, Nutrition, and Population: Kenya. *Country Reports on HPN and Poverty.* Washington, DC: The World Bank.

HALL, A., ANWAR, K. S. & TOMKINS, A. M. 1992. Intensity of reinfection with Ascaris lumbricoides and its implications for parasite control. *Lancet,* 339, 1253-7.

HALL, A., KHANH, L. N., SON, T. H., DUNG, N. Q., LANSDOWN, R. G., DAR, D. T., HANH, N. T., MOESTUE, H., KHOI, H. H. & BUNDY, D. A. 2001. An association between chronic undernutrition and educational test scores in Vietnamese children. *Eur J Clin Nutr,* 55, 801-4.

HAYES, R., MOULTON, L. H. & MORGAN, B. T. J. 2009. *Cluster randomized controlled trials,* New York, Chapman and Hall/CRC Press.

HENRY, F. J. 1988. Reinfection with Ascaris lumbricoides after chemotherapy: a comparative study in three villages with varying sanitation. *Trans R Soc Trop Med Hyg,* 82, 460-4.

HLAING, T., SAW, T. & LWIN, M. 1987. Reinfection of people with Ascaris lumbricoides following single, 6-month and 12-month interval mass

chemotherapy in Okpo village, rural Burma. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 81, 140-6.

HOTEZ, P. J., BUNDY, D. A. P., BEEGLE, K., BROOKER, S., DRAKE, L., SILVA, N. D., MONTRESOR, A., ENGELS, D., JUKES, M., CHITSULO, L., CHOW, J., LAXMINARAYAN, R., MICHAUD, C. M., BETHONY, J., CORREA–OLIVEIRA, R., SHU–HUA, X., FENWICK, A. & SAVIOLI, L. 2006. Helminth Infections: Soil–Transmitted Helminth Infections and Schistosomiasis. *Disease Control Priorities in Developing Countries (2nd Edition),ed.* New York: Oxford University Press.

KANOA, B., GEORGE, E., ABED, Y. & AL-HINDI, A. 2006. Evaluation of the Relationship Between Intestinal Parasitic Infection and Health Education Among School Children in Gaza City, Beit-Lahia Village and Jabalia Refugee Camp, Gaza Strip, Palestine. *The Islamic University Journal (Series of Natural Studies and Engineering),* 14, 39-49.

KATZ, N., CHAVEZ, A. & PELLEGRINO, J. 1972. A simple device for quantitative stool thick-smear technique in Schostosomiasis mansoni. *Rev Inst Med Trop Sao Paulo,* 14, 397-400.

KEISER, J. & UTZINGER, J. 2008. Efficacy of current drugs against soil-transmitted helminth infections: systematic review and meta-analysis. *JAMA,* 299, 1937-48.

KNOPP, S., MOHAMMED, K. A., STOTHARD, J. R., KHAMIS, I. S., ROLLINSON, D., MARTI, H. & UTZINGER, J. 2010. Patterns and risk factors of helminthiasis and anemia in a rural and a peri-urban community in Zanzibar, in the context of helminth control programs. *PLoS Negl Trop Dis,* 4, e681.

LUOBA, A. I., WENZEL GEISSLER, P., ESTAMBALE, B., OUMA, J. H., ALUSALA, D., AYAH, R., MWANIKI, D., MAGNUSSEN, P. & FRIIS, H. 2005. Earth-eating and reinfection with intestinal helminths among pregnant and lactating women in western Kenya. *Tropical Medicine & International Health,* 10, 220-7.

MIGUEL, E. & KREMER, M. 2004. Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities. *Econometrica,* 72.

MORAES, L. R., CANCIO, J. A. & CAIRNCROSS, S. 2004. Impact of drainage and sewerage on intestinal nematode infections in poor urban areas in Salvador, Brazil. *Trans R Soc Trop Med Hyg,* 98, 197-204.

MORAES, L. R., CANCIO, J. A., CAIRNCROSS, S. & HUTTLY, S. 2003. Impact of drainage and sewerage on diarrhoea in poor urban areas in Salvador, Brazil. *Trans R Soc Trop Med Hyg,* 97, 153-8.

OLSEN, A., NAMWANJE, H., NEJSUM, P., ROEPSTORFF, A. & THAMSBORG, S. M. 2009. Albendazole and mebendazole have low efficacy against Trichuris trichiura in

school-age children in Kabale District, Uganda. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 103, 443-446.

OLSEN, A., SAMUELSEN, H. & ONYANGO-OUMA, W. 2001. A study of risk factors for intestinal helminth infections using epidemiological and anthropological approaches. *J Biosoc Sci,* 33, 569-84.

ONYANGO-OUMA, W., AAGAARD-HANSEN, J. & JENSEN, B. B. 2005. The potential of schoolchildren as health change agents in rural western Kenya. *Soc Sci Med,* 61, 1711-1722.

POSTLETHWAITE, N. 1998. The Conditions of Primary Schools: a pilot study in the least developed countries. *International Review of Education,* 44, 1573-0638.

PRUSS, A., KAY, D., FEWTRELL, L. & BARTRAM, J. 2002. Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental Health Perspectives,* 110, 537-542.

PULLAN, R. L., KABATEREINE, N. B., QUINNELL, R. J. & BROOKER, S. 2010. Spatial and genetic epidemiology of hookworm in a rural community in Uganda. *PLoS Negl Trop Dis,* 4, e713.

QUICK, R., VENCZEL, L., MINTZ, E., SOLETO, L., APARICIO, J., GIRONAZ, M., HUTWAGNER, L., GREENE, K., BOPP, C., MALONEY, K., CHAVEZ, D., SOBSEY, M. & TAUXE, R. 1999. Diarrhea prevention in Bolivia through point-of-use disinfection and safe storage: a promising new strategy. *Epidemiol. Infect.,* 122, 83-90.

QUINNELL, R. J. 2003. Genetics of susceptibility to human helminth infection. *Int J Parasitol,* 33, 1219-31.

RABIE, T. & CURTIS, V. 2006. Handwashing and risk of respiratory infections: a quantitative systematic review. *Trop Med Int Health,* 11, 258-67.

SMITH, J. L. & BROOKER, S. 2010. Impact of hookworm infection and deworming on anaemia in non-pregnant populations: a systematic review. *Trop Med Int Health,* 15, 776-95.

SNEL, M. 2004. The Worth of School Sanitation and Hygiene Education. Delft, the Netherlands: International Water and Sanitation Centre (IRC).

STOTHARD, J. R., IMISON, E., FRENCH, M. D., SOUSA-FIGUEIREDO, J. C., KHAMIS, I. S. & ROLLINSON, D. 2008. Soil-transmitted helminthiasis among mothers and their pre-school children on Unguja Island, Zanzibar with emphasis upon ascariasis. *Parasitology,* 135, 1447-55.

SUR, D., SAHA, D. R., MANNA, B., RAJENDRAN, K. & BHATTACHARYA, S. K. 2005. Periodic deworming with albendazole and its impact on growth status and

diarrhoeal incidence among children in an urban slum of India. *Transactions of the Royal Society of Tropical Medicine & Hygiene,* 99, 261-7.

TAYLOR-ROBINSON, D. C., JONES, A. P. & GARNER, P. 2007. Deworming drugs for treating soil-transmitted intestinal worms in children: effects on growth and school performance. *Cochrane Database Syst Rev*, CD000371.

TRAUB, R. J., ROBERTSON, I. D., IRWIN, P., MENCKE, N. & ANDREW THOMPSON, R. C. 2004. The prevalence, intensities and risk factors associated with geohelminth infection in tea-growing communities of Assam, India. *Trop Med Int Health,* 9, 688-701.

UNICEF 2009a. UNICEF Kenya Annual Report. Nairobi.

UNICEF 2009b. Water, Sanitation and Hygiene Annual Report. New York: UNICEF.

UNICEF & INTERNATIONAL WATER AND SANITATION CENTRE 2005. Roundtable Proceedings and Framework for Action. *Water, Sanitation and Hygiene Education for Schools Roundtable Meeting*.

VYAS, S. & KUMARANAYAKE, L. 2006. Constructing socio-economic status indices: how to use principal components analysis. *Health Policy Plan,* 21, 459-68.

WHO 1991. Basic laboratory methods in medical paracitology. Geneva: World Health Organization.

WHO & UNICEF 2010. Progress on Sanitation and Drinking-water: 2010 Update. *WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.* Geneva.

WHO, UNICEF & UNU 2001. Iron deficiency anaemia: assessment, prevention, and control. A guide for programme managers. Geneva: World Health Organization.

6. Household-level water, sanitation, and hygiene risk factors modify the impact of a school-based sanitation and hygiene intervention

Journal: *TBD*

Authorship order: *Matthew C. Freeman, Thomas Clasen, Richard Rheingans, and others TBD*

Stage of publication: *Not yet submitted*

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper:

I wrote the research proposal and study design, and led field data collection, data cleaning, and executed all analyses. I wrote all drafts of the paper.

Candidate's signature

Supervisor or senior author's signature to confirm role as stated above

6.1 Abstract

We assessed the role of household and individual water, sanitation, and hygiene (WASH) conditions in modifying the effect of a school-based WASH program in reducing reinfection with soil-transmitted helminths. The cluster-randomized design was used to assess effect modification of the household WASH characteristics on the main outcomes of prevalence and infection intensity for *Ascaris lumbricoides* and hookworm. Among girls, those without access to a handwashing station, safe water, or an improved latrine at home, those in the intervention showed statistically significant reductions in prevalence of *Ascaris lumbricoides* compared to controls; those with those household WASH characteristics showed reductions, but the effect was statistically significant. Among those with no shoes or without improved latrines at home boys in the intervention had significantly lower levels of hookworm intensity compared to controls, while boys with shoes and an improved latrine at home showed no such effect.

6.2 Introduction

Infection from soil-transmitted helminthes (STH) – intestinal nematodes that have a soil-based life cycle – is widespread in the developing world (Bethony, Brooker et al. 2006). More than 2 billion individuals are infected worldwide with one or more key STHs: *Ascaris lumbricoides* (round worm), *Trichuris trichiura* (whip worm) or *Anscylostoma duodenale and Nectator americanus* (hookworm) (Crompton 1999; Peter J. Hotez, Donald A. P. Bundy et al. 2006).

The majority of the intestinal parasite-related burden of disease is borne by primary school-aged children between the ages of 5 – 12 (Chan, Medley et al. 1994; Murray and Lopez 1996). STHs are responsible for between 12,000 and 135,000 deaths per year and 4.7 to 39.0 million DALYs lost per year (Chan, Medley et al. 1994; WHO 2002; WHO 2004; Bethony, Brooker et al. 2006). Evidence suggests that intense infections may adversely affect cognitive development in schoolchildren and that even light worm burdens may have a marked impact on the health of younger children (Brooker and Bundy 2008).

Fortunately, treatment with chemotherapy is a cheap and effective short-term solution to reduce worm burden (Hall, Khanh et al. 2001; Sur, Saha et al. 2005; Gulani, Nagpal et al. 2007; Taylor-Robinson, Jones et al. 2007; Smith and Brooker 2010). However, reinfection occurs rapidly and there is a growing concern regarding drug resistance (Elkins, Haswell-Elkins et al. 1988; Hall, Anwar et al. 1992; Harhay, Horton et al. 2011). Long-term reductions in worm burden likely require improvements in drinking water quality, improved sanitation, and hygiene behaviors (Bethony, Brooker et al. 2006; Hotez, Bundy et al. 2006).

Cross-sectional studies have revealed helminth infection to be associated with water quality, sanitation, and hygiene behaviors, including handwashing with soap, soil eating (geophagy), and shoe wearing (Traub, Robertson et al. 2004; Gunawardena, Karunaweera et al. 2005; Luoba, Wenzel Geissler et al. 2005; Stothard, Imison et al. 2008). Other risk factors identified that provide

indirect routes for infection include personal genetics, household clustering and parental occupation, poverty, climatic conditions and season, soil type, and age and gender (Hotez, Bundy et al. 2006; Brooker, Kabatereine et al. 2009). Additional risk factors of infection include parents' low educational background and children not living with biological parents (Wordemann, Polman et al. 2006; Ugbomoiko, Dalumo et al. 2009). In one longitudinal study in Malaysia, girls and children without household latrines were found to have significantly higher rates of reinfection six months following deworming (Al-Mekhlafi, Surin et al. 2008).

Few studies have assessed risk factors for STH reinfection in the context of a large scale, longitudinal deworming program (Moraes, Cancio et al. 2004; Knopp, Mohammed et al. 2010). With few exceptions, studies have addressed individual risk factors, household (private) risk factors, community risk factors (public) or spatial patterns (Barreto, Genser et al. 2010; Mascarini-Serra, Telles et al. 2010). Only Moraes and colleagues have attempted to explore the effects of household covariates on a community-level sanitation improvement (Moraes, Cancio et al. 2004). Studies predominantly assess one domain or use cross-sectional analysis to identify associative risk factors.

In this study, we identify how household-level WASH access and individual risk factors including gender modify the impact of a school-based WASH intervention on STH reinfection (Freeman, Clasen et al. 2011).

6.3 Methods

6.3.1 Study setting

This study was conducted in what was at the time, three administrative districts of Nyanza Province in western Kenya. These districts, Kisumu East, Nyando, and Rachuonyo are located near Kisumu City, the third largest city in Kenya. Though the study sites are geographically close, their varied terrain, distance to the Lake Victoria, and rainfall results in a varied risk profile for STH infection. A recent review of worm infection in East Africa found high levels of in Nyanza Province of *A. lumbricoides* (18.5%), *T. trichiura* (11.9%), hookworm (17.6%), *S. mansoni* (8.5%), though there is considerable intra-province variability (Brooker, Kabatereine et al. 2009; Pullan, Gething et al. 2011). The population in the study area is primarily from the Luo ethnic group. Nyanza Province is the second poorest in Kenya; the population mainly relies on subsistence farming and fishing as the main sources of income (Olsen, Samuelsen et al. 2001).

6.3.2 Study design

This study was part of an applied research program assessing the impact of a school-based water treatment, hygiene promotion, and sanitation intervention on health and educational attainment of school pupils. Forty public primary schools in were selected based on access to water supply and sanitation access and randomly allocated to either the intervention or control. By design, eligible schools did not meet the government assigned pupil-latrine

ratio of 30:1 for boys and 25:1 for girls and had a water source within 1km of the school during the dry season. Half of the schools were allocated to an intervention that included teacher training in hygiene promotion, supply of water treatment technology, and construction of latrines. All students in both arms were dewormed with 400 mg of albendazol ten months prior to the survey. Specific intervention components and the impact assessment are described elsewhere (Freeman, Clasen et al. 2011; Freeman, Greene et al. 2011)

Data used for this study was collected from 1,092 children in two years following allocation of a comprehensive school-based water treatment, handwashing promotion, and sanitation intervention. One school was dropped from the study due to a parallel deworming program that interfered with baseline data measurements. The key outcomes of interest were prevalence and intensity of STH infection.

6.3.3 Pupil selection

Children were randomly selected from school enrollment registers in standard grades 3 – 5. Children were eligible if they were between 7 and 13 years old at the time of selection, were dewormed by the project in the previous year, and did not have a sibling also enrolled in the study. This age range was selected because it includes children who have the greatest burden of intestinal STH infection (Chan, Medley et al. 1994; Crompton 1999). Siblings were excluded in order to avoid loss of power due to household clustering of infection (Killewo, Cairncross et al. 1991; Moraes and Cairncross 2004).

School enrollment registers were numbered to include the total number of children in the eligible classes. Slips of papers containing those numbers were selected randomly without replacement. All children not meeting these criteria or who refused deworming drugs for religious or other reasons were excluded from the study.

6.3.4 Data collection

Data for this paper were collected between May 2007 (baseline) and March 2009 (follow-up). At each time point, stool samples were collected from enrolled subjects during the school day. Following collection of the stool from study subjects, all pupils in the school – regardless of enrollment status and intervention group – were dewormed using albendazole. One dose (400mg) of albendazole, a drug shown to reduce worm burden with high efficacy, especially for hookworm and *A. lumbricoides*, was administered by a Government of Kenya public health nurse (Keiser and Utzinger 2008). Since pupils were dewormed following baseline measurements, our outcome of interest is the reinfection of worms.

Stool samples were analyzed using the Kato-Katz technique (Katz, Chavez et al. 1972). Two slides were prepared for each stool sample and read by separate laboratory technicians for fecal egg counts for three worms. Eggs per gram of stool is considered the primary measure of disease morbidity, transmission and exposure are directly related to the intensity of infection (Anderson and May 1991). Morbidity is related to the number of worms harboured by an individual, hence studies in the intensity of infection have the

greatest public health relevance (Brooker and Bundy 2008). Ten percent of the slides were randomly selected for quality control and to address any discrepancies in results.

At follow-up, structured interviews were conducted with pupils to assess WASH knowledge, attitudes, and practices, whether they live with their parents, if their parents are alive, and geophagy. Age, gender, grade, and shoe wearing was recorded.

The day following an interview with a pupil, one enumerator made an unannounced visit to the pupil's home and conducted a structured interview with the female head of the household. If the female head of household was not available, someone with knowledge of the pupil's behaviors and knowledge of the household WASH conditions was interviewed. The respondent was asked about the pupil's WASH access and behaviors at home, water handling and treatment methods, and household demographics such as parent age and education levels. Observations were conducted on latrine presence and conditions and presence of a handwashing station (soap, water, and basin in one place). Household construction materials and assets were recorded; stored water was evaluated for evidence of water treatment using a test for chlorine residual. For interviews of students and parents, tools were designed in English, translated into Dholuo, pilot-tested and back-translated to English.

Structured observations recorded the number and condition of latrines, presence of water for drinking and handwashing, presence of residual

chlorine for water treatment, presence of soap for handwashing, flooring throughout the school compound, and access to electricity.

Data for pupil surveys were collected electronically using Dell x51 personal digital assistants (PDAs) running Microsoft Windows Mobile (Redmond, WA). Surveys were programmed and collected using Syware Visual CE 10 (Cambridge, MA) and downloaded to Microsoft Access 2003. Household surveys, facility surveys, and lab data were collected using paper forms and questionnaires and manually double-entered using Microsoft Access 2003. Data were cleaned and analyzed using SAS v 9.2 (Cary, NC) and STATA v10 (College Station, TX).

6.3.5 Analysis methods

Key dependent variables for this analysis were prevalence and intensity of infection of the three most pervasive soil-transmitted helminths in the study schools: *A. lumbricoides* and hookworm (Hotez, Bundy et al. 2006; Freeman, Clasen et al. 2011). Initial analyses of *T. trichiura* were included to estimate the impact of the intervention; however, due to low levels of infection at follow-up and a biological pattern of infection similar to *A. lumbricoides T. trichiura* is not included in this analysis (Hotez, Bundy et al. 2006).

In order to assess the role of individual and household WASH covariates on modifying the effect of the intervention, we first assessed potential interaction with two demographic indicators: mother's education level (no education/some

primary, completed primary/some secondary, completed secondary) or if the mother is deceased, and economic status.

Economic status was calculated through the development of a wealth index with household construction materials and household assets using principal component analysis (PCA) (Vyas and Kumaranayake 2006). Questions for the index were derived from the demographic and health survey in Kenya (Gwatkin, Rustein et al. 2007). Households were then categorized into quintiles (Filmer and Pritchett 2001).

Individual and household-level WASH covariates assessed for interaction included shoe-wearing, geophagy (soil eating), access to safe water, access to improved sanitation at home, and access to a handwashing station at home. Shoe-wearing was based on observation at the time of data collection. Geophagia, either at home or school was assessed using self-report. Access to safe water was defined as the use of an improved water source (WHO and UNICEF 2010) or detectable chlorine residual in stored water. Improved sanitation was defined as an improved latrine structure within the family compound used exclusively by that family (WHO and UNICEF 2010). A handwashing station was defined as soap and water observed in the same place in the home.

Potential interactions were modeled together against the effect of the intervention, controlling for pupil age, mother's education level or if the mother is deceased, economic status, and school-level aggregate worm levels at baseline. Previous analysis indicated gender as a significant effect modifier of

the impact of the intervention, thus all models are stratified by gender (Freeman, Clasen et al. 2011).

To assess the separate, adjusted effects and interaction of demographics on the school-based intervention against the fully interacted model, we employed likelihood ratio tests to assess goodness of fit (Kleinbaum and Klein 2002). For multi-level multivariable regression, we employed generalized estimating equations; standard errors were adjusted for school-level clustering (Hayes, Moulton et al. 2009).

Interaction effects are assessed in an adjusted model and β coefficients are reported. For full models, beta coefficients (β) represent the interaction term, where a negative number represents lower prevalence or intensity of infection for the pupils with the condition of interest (ie, "no handwashing station") as a result of the intervention relative to those without the condition of interest (ie, "handwashing station"). Models were adjusting for all other WASH characteristics, pupil age, economic status, and maternal mortality and education level, stratified by gender. Models with geophagy were only presented for infection prevalence among girls; models for boys and those of intensity of infection failed to converge.

Logistic regression was used to model prevalence of infection; negative binomial linear regression was employed for intensity of infection due to over-dispersion of outcomes (Anderson and Schad 1985).

To assess estimates of effect, controlling for all interaction, we employed the following standard logistic regression model:

$$log\frac{\pi_{ij}}{1-\pi_{ij}} = \alpha + G_i\theta + H_j\varphi + G_iH_j\omega + W_i\delta + X_j\gamma$$

where π_{tij} is the probability of school absence of individual *j* from school *i* at follow-up, G_i indicates assignment to the treatment group, H_j are individual and household WASH covariates, W_i is the baseline level prevalence of STH infection, and X_j represents demographic characteristics.

For count outcomes of eggs per gram of feces, we used a negative binomial distribution to account for over-dispersion and test the impact of the intervention on population-level intensity of infection (Anderson and Schad 1985). The log-linear model takes the form:

$$log\ (E(Y_{ij}|G_i, H_j, W_i, X_j)) = \alpha + G_i\theta + H_j\varphi + G_iH_j\omega + W_i\delta + X_j\gamma$$

where $E(Y_{ij})$ is the expected value of Y_{ij} (eggs per gram of feces) of individual *j* from school *i* at follow-up given other covariates of interest, and other regressors are similar to those described above.

In order to calculate the estimates of effect for models, controlling for multiple interaction terms the linear combination of effects were calculated using these formulae:

$$(1)\ \beta\ estimate\ (H_1 = 1, \bar{X},\ \bar{H}_{2-5}) = \theta_G + \varphi_{H1} + \omega_{H2}\overline{H_2} + \ldots + \omega_{H5}\overline{H_5}$$

$$(2)\ \beta\ estimate\ (H_1 = 0, \bar{X},\ \bar{H}_{2-5}) = \theta_G + \omega_{H2}\overline{H_2} + \ldots + \omega_{H5}\overline{H_5}$$

where φ_{H1} is included for those where WASH characteristic $\mathrm{H1} = 1$ and excluded when WASH characteristic $\mathrm{H1} = 0$, and $\bar{H}2 - \bar{H}5$ are mean prevalence of the other WASH covariates for each gender.

β estimates were exponentiated to provide odds ratios (OR) for binary prevalence data and incidence rate ratios (IRR), for count data of infection intensity. ORs can be interpreted as the ratio of the probability of infection with worms in the intervention versus the control, when H_{2-5} are set at their mean levels for each gender. IRR are interpreted as the ratio of the probability of the epg of feces count in intervention versus control, when H_{2-5} are set at their mean levels for each gender.

6.4 Results

6.4.1 Prevalence and intensity of infection of helminth infections

Baseline data for this study population is reported elsewhere (Freeman, Clasen et al. 2011). Binary analysis of individual and household risk factors for prevalence of *A. lumbricoides* and hookworm are shown in Table 1. For *A. lumbricoides*, only having an improved latrine (Risk ratio [RR] 0.41, 95% confidence interval [CI] 0.19-0.91) and mother having finished primary school (RR 0.65, CI 0.43-0.99) were found to be statistically protective. For hookworm prevalence, shoe-wearing (RR 0.40, CI 0.25-0.65) and access to

safe water (RR 0.65, CI 0.31-1.08) were found to be protective, while geophagy (RR 1.77, CI 1.05-2.98) was a risk factor.

6.4.2 Household economic status and demographics

Basic models of the impact of the intervention on helminth infection, stratified by gender, are reported for *A. lumbricoides* (Table 2) and hookworm (Table 3). There was no statistical difference of the impact of the intervention for prevalence of *A. lumbricoides* for girls (Odds Ratio [OR] 0.46, CI 0.18 – 1.20) or for boys (OR 0.93, CI 0.39-2.22), controlling for age and baseline worm burden (Table 2). The interaction effect of mother's education and mortality was not found to be significant, and was kept in as an *a priori* determined potential confounder. Economic quintile was a marginally significant effect modifier for girls. The secular trend for economic quintile and *A. lumbricoides* prevalence revealed reduced infection for less poor girls. Those in the poorest wealth quintile were most likely to benefit from the intervention (OR 0.13, CI 0.02-1.07), while effects in the other quintiles were not significant, with those in the least poor wealth quintile were not significant. For boys, the secular trend was similar, though none of the effect estimates were significant.

A model controlling for age and baseline worm level revealed that the intervention increased the prevalence of hookworm among girls (OR 1.98, CI 0.94-4.18), but had no effect on boys (OR 1.10, CI 0.56 – 2.19) (Table 3). There was evidence of secular trends of increased wealth and reduced infection for both boys and girls. There were no significant individual effect estimates for by economic quintile for girls; among boys in the lowest

economic quintile, however, reduction in infection relative to those in the control schools was marginally insignificant (OR 0.49, CI 0.22-1.09).

6.4.3 Effect modification of individual and household WASH characteristics

When interaction terms for the household and individual-level WASH covariates were added to the model, statistical significance of the modifying effect of economic status was no longer significant (data not shown). Likelihood ratio tests revealed no statistical improvement in model fit for prevalence of *A. lumbricoides* among girls (p=0.39) or boys (p=0.85), or for hookworm among girls (p=0.82) or boys (p=0.64). As such, economic status was included in subsequent models as a covariate, but not as an effect modifier. Removal of wealth index from the models did not substantially change the key parameters of interest or model fit; however, it remained in the model as an *a priori* determined covariate (data not shown).

The effect modification of individual and household-level WASH characteristics on the effect of the school-level WASH intervention by gender and type of STH are shown in Tables 4 – 7 and summarized in Table 8. All interactions were modeled together to control for potential correlation between covariates. Figure 1 shows the statistically significant correlations and their direction among demographic characteristics, which are considered indirect risk factors for STH exposure, and household and individual WASH covariates, which are directly responsible for fecal exposure and risk of STH infection. Shoe-wearing was significantly associated with access to safe water and economic status (positive association), as well as access to a

latrine and a handwashing station (negative association). Safe water access was positively associated with a household handwashing station, maternal education, and economic status. Economic quintile was positively associated with all explored factors except geophagy. Models with geophagy were only presented for infection prevalence among girls; models for boys and those of intensity of infection failed to converge.

Girls without access to a handwashing station at home exhibited a greater reduction in both the prevalence (β -1.30, CI -2.80; 0.18) and intensity of infection (β -8.60, CI -13.00; -3.70) (Table 4). Similarly, those with those without safe water at home showed greater reductions in prevalence (β -1.40, CI -2.70;-0.16) and infection intensity (β -5.60, CI -12.00; 0.76). However, secular effects showed that girls without a handwashing location or safe water had higher levels of *A. lumbricoides* infection. Access to a household latrine did not significantly modify the effect of the intervention on *A. lumbricoides* infection for girls, nor did shoe-wearing or geophagy.

Among boys, there were no statistically significant interaction effects for the effect of the intervention on *A. lumbricoides* infection (Table 5). However, for intensity of infection, the intervention had a greater impact on boys without a handwashing station at home (β -4.30, CI -7.80; -0.81) and those without an improved latrine (β -9.00, CI -12.00; -5.20) than those with facilities at home. In contrast, boys without access to a safe water source benefitted less from the intervention than those with one (β 3.95, CI 0.61; 7.30).

No household WASH characteristics were found to modify the effect of the intervention on hookworm prevalence among girls (Table 6). However, those without a latrine benefitted more than those with a latrine at home (β -4.00, CI –8.40; 0.42), as did those without shoes (β -3.40, CI -6.20; -0.54).

For boys, not having access to a latrine led to reduced prevalence of hookworm infection as a result of the intervention, relative to those with a latrine (β -1.70, CI -3.60; 0.23) (Table 7). Those boys without safe water, an improved latrine, or shoes revealed a secular trend towards greater hookworm prevalence. A number of Individual and household WASH conditions modified the effect of the intervention on intensity of infection for boys, including no handwashing station (β 5.27, CI 1.60; 9.48), no safe water (β -3.20, CI -5.30; 1.10), no improved latrine (β -3.40, CI -5.70; -1.00), and no shoes (β -2.80, CI -4.80; -0.85).

6.4.4 Multivariable models

Estimates of effect, stratified by gender, for the impact of the school-based water quality, sanitation, and hygiene intervention are found in Table 8. Girls without a handwashing station had a significant reduction in prevalence of *A. lumbricoides* (OR 0.17, CI 0.06-0.47) compared to controls, as opposed to those with a handwashing station (OR 0.85, CI 0.29-2.44). That trend was similar for girls without access to safe water (OR 0.11, CI 0.03-0.35) or a latrine (OR 0.38, CI 0.17-0.87) compared to those with safe water (OR 0.61, CI 0.26-1.41) or a latrine (OR 0.25, CI 0.05-1.42). Girls with shoes showed a significant reduction in *A. lumbricoides* prevalence (OR 0.23, CI 0.09-0.57)

compared to those without (OR 0,85, CI 0.26-2.77). These trends were consistent with models for intensity of *A. lumbricoides* infection for girls.

There were no significant effects of the intervention for reduction of *A. lumbricoides* infection among any of the WASH access sub-populations for boys (Table 8). boys without improved latrines showed a reduction in (IRR 0.01, CI 0.00-0.20) and boys with an improved latrine (IRR 148.04, CI 5.02-4359.00). Similarly, boys in the intervention schools with a handwashing station showed a reduction in intensity of *A. lumbricoides* infection (incidence rate ratio [IRR] 0.10, CI 0.01-1.09), while those without a handwashing station showed an increase in infection intensity (IRR 2.77, CI 0.21-36.20), though neither of these effects were significant. Boys without shoes in the intervention had a significant reduction in IRR compared to controls (IRR 0.04, CI 0.00-0.81), while there was no effect on boys with shoes (IRR 1.07, CI 0.00-0.81).

For hookworm prevalence among girls those in the intervention schools had a general increase in infection compared to those in control (Table 8). Sub-populations with greater odds of prevalence included those with an improved latrine at home (OR 16.88, CI 1.00-285.00), and those who wore shoes (OR 3.61, CI 1.01-12.90). Those with or without a handwashing station or with or without access to safe water revealed similar estimates of effect as a result of the intervention. These trends were similar for estimates of intensity of hookworm infection for girls.

Among boys, those with a latrine showed statistically significant increases in hookworm infection as a result of the intervention (OR 6.54, CI 0.93-45.80), while those without a latrine not significantly affected (OR 1.10, CI 0.41-3.00); similarly, those with shoes showed a similar level of effect (OR 9.61, CI 0.84-109.00) (Table 8). Boys without a handwashing station at home showed an increase in intensity of hookworm infection (IRR 4.20, CI 1.23-14.20), while reductions were found among those without an improved latrine (IRR 0.14, CI 0.03-0.74) and without shoes (IRR 0.09, CI 0.01-1.44).

6.5 Discussion

In this paper, we present the role that household-based WASH access has on the effect of a school-based WASH improvements designed to reduce STH infection. Previous studies have presented risk factors of helminth infection through analysis of cross-sectional findings or, in some cases, via longitudinal design. Lack of access to sanitation at home, poverty, and poor parental education are consistently cited as risk factors for STH infection (Traub, Robertson et al. 2004; Gunawardena, Karunaweera et al. 2005; Stothard, Imison et al. 2008). To our knowledge, this is the first study to explore effect modification of household-based WASH status on a school-based WASH intervention through an experimental design. Our purpose was to explore these risk factors with an eye to possible routes and critical pathway for risk of infection among a key age group.

Though there was a general trend for improved benefit of the intervention for poorer pupils and those without household WASH access, our results do not

reveal a singular story of how exposure at home modify the results from our trial of school-based WASH improvements. The effect of the intervention on individual worm species is somewhat consistent, revealing clear gender-specific effects. However, taken together, it is difficult to assess an overall pattern that matches with our understanding of the biology of the worms, the behaviors of children, and the established risk factors for public and private transmission domains.

The one consistent pattern across genders was that that the lack of an improved latrine at home led to lower reinfection prevalence and intensity of infection for hookworm, compared to pupils with a latrine at home. One possible reason is that those without a latrine at home are more likely to take advantage of new school latrines, while those with a latrine at home may still chose to use that option. As such, one latrine, either at home or school may be sufficient to reduce exposure.

The interactions with household WASH access reveal some basic, though not thoroughly consistent patterns of effect. For girls, the lack of a handwashing station at home increased the protective effect of the school-based intervention (led to reduced reinfection). Similarly, those without safe water at home benefitted more from the improved access at school, but only for *A. lumbricoides.* Among boys, the pattern for access to a handwashing station and safe water was nearly opposite. Previous studies have pointed to household clustering as evidence that children are the likely disseminators of *A. lumbricoides* to the home (Killewo, Cairncross et al. 1991; Moraes and

Cairncross 2004). The strong gender-specific effect that we observed points to the susceptibility of girls to home hygiene and sanitation conditions and may be related to their household responsibilities as cooks, caretakers of infants, and cleaners of the home (Al-Mekhlafi, Surin et al. 2008).

The association between wealth status and worm infection revealed a pattern of increasing wealth and reduced infection found elsewhere (Hotez, Bundy et al. 2006). Those pupils in the highest economic status had lower odds of *A. lumbricoides* and hookworm. However, of note was the trend that with regards to *A. lumbricoides* poorer pupils benefitted more from the intervention than wealthier pupils. For the other worms, that same trend didn't follow, though those with higher economic status – quintiles 4 and 5 – fared worse from the intervention than those in the control. Wealth itself is not a mechanism for STH infection; it must be mitigated through some sort of fecal exposure. For poorer students to benefit more from the intervention, it follows that improving access at school may be sufficient to reduce infection, as this new access at the school is superior to their access at home. On the other hand, improved access at school for less poor students may present an opportunity for increased exposure relative to their access at home.

Further research is necessary to confirm the effects we observed in our study, to better understand the operative mechanisms, and to reduce the mitigating effects.

6.4.1 Limitations

We relied on objective measures of exposure: observations of latrines, handwashing stations, chlorine residual, and shoe-wearing. However, these observations were collected at single time points and may not reflect consistent access. Additionally, the presence of a latrine, for example, does not guarantee use (Olsen, Samuelsen et al. 2001). There are cultural taboos associated with sharing latrines and latrines may be locked when adults are not at home. Indeed, improved sanitation and hygiene access will not have an effect if the latrines are not used correctly (Ugbomoiko, Dalumo et al. 2009).

A second limitation is the lack of longitudinal data. Reinfection with worm infection is known to be correlated with previous infection (Anderson and Schad 1985). Due to logistical considerations, we relied on the school-aggregated baseline for each worm infection. Only children who were dewormed in the previous round were included in the analysis, thus we relied on randomization to account for selection of more susceptible individuals. However, the use of an aggregated baseline is an imprecise measure that may bias our results. Specifically, while ten months following deworming is considered sufficient to achieve reinfection to baseline levels, the precise reinfection depends on the intensity of parasite transmission (R_0), treatment efficacy and the percentage of the community worm burden eliminated during deworming (Anderson and May 1991; Hotez, Bundy et al. 2006).

6.4.2 Conclusions

These data provide some basic, though not overwhelming evidence of the role of household WASH access in influencing the effect of a school-based WASH improvement on reducing worm reinfection. In general, pupils without access to WASH at home benefitted more from the intervention. Some attempts have been made to understand how background rates of disease burden influence the role of public or private WASH conditions (Eisenberg, Scott et al. 2007). However, few studies of the WASH benefits account for exposure in both the pubic and private domain, a factor necessary to better understand the routes of exposure of parasitic infection and other WASH related diseases (Cairncross, Blumenthal et al. 1996). Additional investigation into transmission routes of fecal exposure among school-going children that include an assessment of both the household and school risk factors is warranted.

6.5 Tables and Figures

Figure 6-1: Statistical correlations between demographic and WASH covariates

	Shoes	Geophagy	Safe Water	Private latrine	Household latrine	Maternal education
Geophagy						
Safe Water	+++					
Private latrine	--					
Handwashing station	---		++			
Maternal eduction§			+++			
Quintile§	+++		+++	+++	+++	na

Positive (+) and inverse (-) correlations assessed using X^2 test and (§) variance-weighted least squares regression (test for trend). ++ = significant at 0.05, +++ = significant at 0.01

Table 6-1: Prevalence of soil-transmitted helminth infection and its associated risk factors among pupils ten months following mass-spectrum deworming

Variable		n	Ascaris Cases (%)	Ascaris Risk Ratio (95% CI)	Hookworm Cases (%)	Hookworm Risk Ratio (95% CI)
Pupil variables		1095				
Gender	Boys	520	29 (5.7)	1.58 (1.09-2.26)	35 (6.4)	0.83 (0.57-1.20)
	Girls	575	52 (8.9)		40 (7.8)	
Pupil WASH attitudes and practices						
Shoe wearing	Shoes	712	55 (7.5)	0.99 (0.49-1.98)	35 (4.4)	**0.40 (0.25-0.65)**
	No shoes	358	26 (7.5)		36 (11.0)	
Geophagy (soil eating)	Yes	138	15 (11.1)	1.62 (0.83-3.18)	12 (11.3)	**1.77 (1.05-2.98)**
	No	955	66 (6.8)		62 (6.3)	
Household WASH access						
Handwashing station	Present	431	35 (7.4)	1.01 (0.60-1.67)	27 (6.3)	0.83 (0.48-1.43)
	Absent	658	46 (7.4)		48 (7.7)	
Improved latrine	Yes	394	20 (3.8)	**0.41 (0.19-0.91)**	20 (5.0)	0.61 (0.33-1.12)
	No	694	16 (9.2)		55 (8.1)	
Safe water	Present	677	40 (6.2)	0.65 (0.35-1.20)	39 (5.6)	**0.58 (0.31-1.08)**
	Absent	418	41 (9.5)		36 (9.7)	
Household demographics						
Socio-economic quintile	Poorest 20%	329	28 (8.3)	ref	30 (10.1)	ref
	Lower middle 20%	121	11 (8.2)	0.97 (0.48-2.00)	7 (5.1)	0.51 (0.21-1.21)
	Middle 20%	198	11 (6.0)	0.72 (0.25-2.10)	13 (7.4)	0.73 (0.30-1.75)
	Upper middle 20%	216	12 (5.8)	0.70 (0.38-1.28)	14 (5.8)	0.57 (0.25-1.29)
	Top 20%	219	18 (7.4)	1.02 (0.46-2.29)	11 (4.4)	0.43 (0.20-0.94)
Mother education	No education	423	38 (9.3)	ref	29 (7.2)	ref
	Finished primary	472	31 (6.1)	**0.65 (0.43-0.99)**	32 (7.0)	0.97 (0.53-1.78)
	Finished secondary	67	4 (9.3)	1.00 (0.19-5.25)	75 (7.1)	0.39 (0.05-2.93)
Mother alive	Alive	43	2 (3.0)	2.60 (0.53-12.78)	5 (10.6)	0.69 (0.21-2.72)

Unadjusted prevalence estimates of worm infection for risk factors across internvetion and control group at follow-up.
Risk ratios significant at α=0.05 in bold

Table 6-2: The effect of the intervention on prevalence of infection, stratified by wealth index on prevalence of infection with A. lumbricoides

	Girls					Boys				
Variable	**OR**	**(95% CI)**	***p***	**OR**	**(95% CI)**	***p***	**OR**	**(95% CI)**	***p***	**OR**	**(95% CI)**	***p***
	n=574			n=569			n=517			n=487		
Intervention^	0.46	0.18-1.20					0.93	0.39-2.22				
Age	1.09	0.78-1.54		1.07	0.75-1.54		1.14	0.78-1.68		1.16	0.81-1.67	
Baseline worm level	62.60	6.70-586.00	***	112.00	14.50-873.00	***	121.00	9.37-1,564.00	***	141.00	10.80-1,831.00	***
Effect of the intervention vs. control within each quintile§												
Poorest quintile				0.13	0.02-1.07	*				0.56	0.17-1.89	
Poorer quntile				0.36	0.06-2.16					1.18	0.13-10.90	
Middle quintile				0.49	0.09-2.80					1.08	0.10-12.10	
Less poor quntile				0.40	0.04-4.08					1.82	0.19-17.40	
Least poor quintile				1.67	0.51-5.55					0.70	0.15-3.38	
Relative effect of wealth on reinfection												
Poorest quintile				ref						ref		
Poorer quntile				0.89	0.22-3.63					0.58	0.12-2.74	
Middle quintile				0.42	0.08-2.21					0.45	0.13-1.59	
Less poor quntile				0.32	0.08-1.34					0.52	0.09-3.01	
Least poor quintile				0.35	0.09-1.33					1.04	0.26-4.22	
Additional covariates												
Mother: no education / some primary				ref						ref		
completed primary / some secondary				0.62	0.30-1.28					0.63	0.25-1.56	
At least completed secondary				2.07	0.30-14.20					na	na	
Mother deceased (vs. no education)				0.63	0.18-2.17					0.31	0.05-1.82	

*^ The intervention term reports the estimate of effect for basic models, controlling for age and baseline worm burden, stratified by gender. § Interaction models assess the effect of the intervention separately for each wealth quintile, controlling for secular trend in wealth quintile, age, mother's education, mother alive, and baseline worm level. For that reason, no "intervention" term is reported. There were too few boys with mothers who completed secondary education, so no effect estimate is reported. *significance at a<0.1. **significance at a<0.05. ***significance at a<0.01*

Table 6-3: The effect of the intervention on prevalence of infection, stratified by wealth index on prevalence of infection with Hookworm

	Girls					Boys				
Variable	**OR**	**(95% CI)**	***p***	**OR**	**(95% CI)**	***p***	**OR**	**(95% CI)**	***p***	**OR**	**(95% CI)**	***p***
	n=574			n=569			n=517			n=487		
Intervention^	1.98	0.94-4.18	*				1.10	0.56-2.19				
Age	1.23	0.96-1.59	*	1.23	0.98-1.54	*	0.96	0.71-1.32		0.96	0.72-1.29	
Baseline worm level	3.45	0.58-20.40		3.27	0.46-23.10		8.17	1.86-35.70	***	9.08	2.01-40.90	***
Effect of the intervention vs. control within each quintile§												
Poorest quintile				2.01	0.55-7.36					0.49	0.22-1.09	*
Poorer quntile				1.02	0.08-13.80					0.88	0.09-9.08	
Middle quintile				1.13	0.10-12.60					1.00	0.18-5.53	
Less poor quntile				4.99	0.61-40.70					2.69	0.33-22.30	
Least poor quintile				2.12	0.19-24.40					4.03	0.31-52.00	
Relative effect of wealth on reinfection												
Poorest quintile				ref						ref		
Poorer quntile				0.57	0.09-3.83					0.46	0.12-1.81	
Middle quintile				0.82	0.10-7.06					0.66	0.14-3.09	
Less poor quntile				0.23	0.02-3.09					0.32	0.06-1.91	
Least poor quintile				0.32	0.02-4.46					0.19	0.02-1.71	
Additional covariates												
Mother: no education / some primary				ref						ref		
completed primary / some secondary				1.47	0.58-3.74					0.84	0.36-2.01	
At least completed secondary				0.78	0.07-8.40					na	na	
Mother deceased (vs. no education)				1.64	0.44-6.07					1.31	0.54-3.24	

*^ The intervention term reports the estimate of effect for basic models, controlling for age and baseline worm burden, stratified by gender. § Interaction models assess the effect of the intervention separately for each wealth quintile, controlling for secular trend in wealth quintile, age, mother's education, mother alive, and baseline worm level. For that reason, no "intervention" term is reported. There were too few boys with mothers who completed secondary education, so no effect estimate is reported. *significance at a<0.1. **significance at a<0.05. ***significance at a<0.01*

Table 6-4: Design models and interacted model for prevalence and intensity of infection for *A. lumbricoides* prevalence and intensity of infection among girls

	Prevalence						Intensity of infection					
	Design model			Interacted model			Design Model			Interacted model		
Variable	**β coeff**	**(95% CI)**	***p***	**β coeff**	**(95% CI)**		**β coeff**	**(95% CI)**	***p***	**β coeff**	**(95% CI)**	**p**
	n=574			n=560			n=571			n=559		
Intervention	-0.70	-1.70;0.18	0.11	-0.10	-2.10;1.96	0.91	-1.40	-2.50;-0.22	0.02	3.74	-3.40;10.90	0.30
No handwashing station at home				0.22	-0.61;1.06	0.58				-0.40	-2.20;1.37	0.64
No handwashing station * intervention				-1.30	-2.80;0.18	0.08				-8.60	-13.00;-3.70	<0.01
No safe water at home				0.79	-0.01;1.59	0.05				5.33	0.22;10.40	0.04
No safe water*intervention				-1.40	-2.70;-0.16	0.02				-5.60	-12.00;0.76	0.08
No Improved latrine (not shared)				0.94	-0.37;2.25	0.15				7.01	3.75;10.20	<0.01
No improved latrine * intervention				0.19	-1.70;2.13	0.83				-3.80	-9.00;1.37	0.14
No shoes				0.04	-0.87;0.96	0.92				-1.40	-5.60;2.71	0.47
No shoes * intervention				1.00	-0.31;2.32	0.13				2.93	-1.80;7.72	0.22
Geophagy (soil eating)				0.58	-0.50;1.66	0.28						
Geophagy * intervention				-0.80	-3.00;1.31	0.43						
Age	0.09	-0.25;0.44	0.58	0.07	-0.29;0.44	0.68	0.09	-0.36;0.56	0.05	-0.60	-1.40;0.22	0.14
Economic status: poorest quintile				ref						ref		
Poorer quntile				0.28	-0.98;1.55	0.65				5.36	2.51;8.20	<0.01
Middle quintile				-0.50	-1.90;0.85	0.42				-3.50	-8.20;1.28	0.14
Less poor quntile				-0.60	-1.60;0.31	0.17				0.36	-4.40;5.13	0.87
Least poor quintile				0.29	-0.97;1.56	0.64				0.21	-2.30;2.80	0.86
Mother alive and eduction: mother dead				ref						ref		
No education/some primary				0.54	-0.88;1.98	0.44				-1.60	-5.70;2.32	0.39
Completed primary/some secondary				0.26	-1.10;1.66	0.69				-1.10	-5.20;2.96	0.57
At least completed secondary				0.94	-1.10;3.03	0.36				-2.50	-7.30;2.35	0.30
Baseline worm level	4.13	1.90;6.37	<0.01	4.69	3.05;6.33	<0.01	0.00	0.00;0.00	0.05	0.00	0.00;0.00	0.01

Interaction models controlling for all interaction terms and covariates

Table 6-5: Design models and interacted model for prevalence and intensity of infection for *A. lumbricoides* prevalence and intensity of infection among boys

	Prevalence						Intensity of infection					
	Uninteracted model			Interacted model			Design Model			Interacted model		
Variable	**β coeff**	**(95% CI)**	***p***	**β coeff**	**(95% CI)**		**β coeff**	**(95% CI)**	***p***	**β coeff**	**(95% CI)**	**p**
	n=517			n=473			n=513			n=491		
Intervention	0.00	-0.93;0.80	0.87	-0.20	-3.20;2.68	0.83	0.05	-1.50;1.64	0.94	7.12	1.04;13.20	0.02
No handwashing station at home				0.00	-1.20;1.28	0.99				4.10	1.00;7.22	0.01
No handwashing station * intervention				1.03	-1.10;3.24	0.34				-4.30	-7.80;-0.81	0.01
No safe water at home				0.29	-1.30;1.96	0.72				3.17	0.70;5.65	0.01
No safe water*intervention				0.37	-1.70;2.46	0.72				3.95	0.61;7.30	0.02
No Improved latrine (not shared)				1.06	-0.18;2.31	0.09				8.20	5.99;10.40	<0.01
No improved latrine * intervention				-0.70	-2.90;1.45	0.49				-9.00	-12.00;-5.20	<0.01
No shoes				-0.10	-2.20;1.90	0.85				-0.90	-4.40;2.67	0.61
No shoes * intervention				-0.30	-2.80;2.00	0.73				-2.70	-7.90;2.39	0.28
Geophagy (soil eating)												
Geophagy * intervention												
Age	0.13	-0.25;0.52	0.49	0.13	-0.23;0.51	0.46	0.16	-0.18;0.52	0.05	-0.40	-1.10;0.24	0.19
Economic status: poorest quintile												
Poorer quntile				0.05	-1.10;1.25	0.93				-3.90	-8.00;0.15	0.05
Middle quintile				-0.30	-1.70;1.06	0.63				-1.90	-4.80;0.93	0.17
Less poor quntile				0.14	-1.50;1.82	0.86				-4.10	-6.30;-1.80	<0.01
Least poor quintile				0.47	-0.72;1.67	0.43				3.03	0.65;5.41	0.01
Mother alive and eduction: mother dead												
No education/some primary				1.06	-0.58;2.71	0.19				-0.70	-4.10;2.70	0.66
Completed primary/some secondary				0.50	-1.10;2.20	0.55				-3.60	-7.00;-0.36	0.03
At least completed secondary										-26.00	32.00;-20.00	<0.01
Baseline worm level	4.79	2.23;7.35	<0.01	5.74	3.54;7.93	<0.01	0.00	0.00;0.00	0.04	0.00	0.00;0.00	<0.01

Interaction models controlling for all interaction terms and covariates

Table 6-6: Design models and interacted model for prevalence and intensity of infection for hookworm prevalence and intensity of infection among girls

	Prevalence						Intensity of infection					
	Uninteracted model			Interacted model			Design Model			Interacted model		
Variable	β coeff	(95% CI)	*p*	β coeff	(95% CI)	p	β coeff	(95% CI)	*p*	β coeff	(95% CI)	*p*
	n=574			n=560			n=571			n=559		
Intervention	0.69	-0.06-1.43	0.07	3.08	-0.12;6.28	0.05	1.27	0.30;2.25	0.01	7.67	5.28;10.00	0.00
No handwashing station at home				0.38	-0.93;1.69	0.56				2.45	0.36;4.53	0.02
No handwashing station * intervention				-0.10	-1.80;1.51	0.85				-1.50	-6.50;3.48	0.54
No safe water at home				0.61	-0.53;1.75	0.28				0.04	-2.10;2.19	0.96
No safe water*intervention				0.03	-1.70;1.78	0.96				0.26	-1.90;2.50	0.81
No Improved latrine (not shared)				1.69	-1.10;4.57	0.24				2.69	0.57;4.81	0.01
No improved latrine * intervention				-2.30	-5.50;0.76	0.13				-4.00	-8.40;0.42	0.07
No shoes				1.67	0.12;3.22	0.03				4.15	2.82;5.48	0.00
No shoes * intervention				-0.40	-2.20;1.31	0.58				-3.40	-6.20;-0.54	0.02
Geophagy (soil eating)				0.96	-0.84;2.77	0.28						
Geophagy * intervention				-0.30	-2.50;1.80	0.72						
Age	0.22	-0.03-0.47	0.09	0.19	-0.05;0.46	0.12	0.46	0.09;0.82	0.01	0.64	0.04;1.24	0.03
Economic status: poorest quintile												
Poorer quntile				-0.60	-2.20;0.87	0.37				1.96	-0.58;4.51	0.12
Middle quintile				-0.40	-1.70;0.90	0.50				0.00	-2.10;2.14	0.99
Less poor quntile				-0.88	-1.90;0.16	0.09				0.20	-1.60;2.04	0.82
Least poor quintile				-1.00	-2.40;0.36	0.13				0.38	-2.20;2.97	0.76
Mother alive and eduction: mother dead												
No education/some primary				-0.30	-2.00;1.32	0.67				-2.40	-4.30;-0.54	0.01
Completed primary/some secondary				0.00	-1.20;1.28	0.99				-2.30	-4.20;-0.56	0.01
At least completed secondary				-0.60	-3.80;2.52	0.68				-3.90	10.00;2.64	0.23
Baseline worm level	1.23	-0.53-3.01		1.17	-0.73;3.08	0.22	0.00	0.00;0.01	0.27	0.00	0.00;0.01	0.58

Interaction models controlling for all interaction terms and covariates

Table 6-7: Design models and interacted model for prevalence and intensity of infection for hookworm prevalence and intensity of infection among boys

	Prevalence						Intensity of infection					
	Uninteracted model			Interacted model			Design Model			Interacted model		
Variable	β coeff	(95% CI)	*p*	β coeff	(95% CI)	p	β coeff	(95% CI)	*p*	β coeff	(95% CI)	*p*
	n=517			n=473			n=513			n=491		
Intervention	0.10	-0.58-0.79	0.76	2.37	-0.32;5.08	0.08	-2.40	-3.70;-1.10	0.00	0.94	-3.90;5.83	0.69
No handwashing station at home				-0.10	-1.60;1.41	0.87				-4.00	-6.10;-1.90	0.00
No handwashing station * intervention				0.62	-1.10;2.44	0.49				5.27	1.06;9.48	0.01
No safe water at home				1.44	0.09;2.80	0.03				3.63	1.47;5.78	0.00
No safe water*intervention				-1.30	-3.10;0.52	0.15				-3.20	-5.30;-1.10	0.00
No Improved latrine (not shared)				1.80	-0.04;3.64	0.05				5.42	3.69;7.16	0.00
No improved latrine * intervention				-1.70	-3.60;0.23	0.08				-3.40	-5.70;-1.00	0.00
No shoes				1.41	-0.06;2.89	0.06				2.12	0.50;3.75	0.01
No shoes * intervention				-0.90	-2.70;0.85	0.28				-2.80	-4.80;-0.85	0.00
Geophagy (soil eating)												
Geophagy * intervention												
Age	0.00	-0.34-0.28	0.83	0.00	-0.34;0.32	0.94	-0.40	-0.86;0.04	0.07	0.10	-0.38;0.59	0.67
Economic status: poorest quintile												
Poorer quntile				0.00	-1.40;1.27	0.89				0.76	-1.70;3.27	0.54
Middle quintile				0.15	-0.83;1.15	0.74				-0.90	-2.20;0.47	0.19
Less poor quntile				0.01	-1.30;1.40	0.98				1.94	0.40;3.49	0.01
Least poor quintile				0.15	-0.86;1.18	0.75				1.50	-0.40;3.42	0.11
Mother alive and eduction: mother dead												
No education/some primary				-0.30	-1.40;0.76	0.54				0.00	-2.10;2.03	0.94
Completed primary/some secondary				-0.50	-1.60;0.61	0.35				-0.30	-2.20;1.67	0.75
At least completed secondary				na	na	na				-4.30	-7.20;-1.40	0.00
Baseline worm level	2.10	0.63-3.57		1.80	0.07;3.53	0.04	0.01	0.00;0.01	0.00	0.01	0.00;0.01	0.03

Interaction models controlling for all interaction terms and covariates

Table 6-8: Summary of adjusted beta estimates for potential effect modification of household WASH conditions between intervention arm and STH reinfection, stratified by gender

	Ascaris				Hookworm			
	Prevalence		Intensity of infection		Prevalence		Intensity of infection	
	β	*p*	β	*p*	β	*p*	β	*p*
Girls (n=561)								
No handwashing station	**-1.30**	**0.08**	**-8.60**	**<0.01**	-0.10	0.85	-1.50	0.54
No safe water	**-1.40**	**0.02**	**-5.60**	**0.08**	0.03	0.96	0.26	0.81
No improved latrine	0.19	0.83	-3.80	0.14	-2.30	0.13	**-4.00**	**0.07**
No shoes	1.00	0.13	2.93	0.22	-0.40	0.58	**-3.40**	**0.02**
Geophagy	0.58	0.28			0.96	0.28		
Boys (n=499)								
No handwashing station	1.03	0.34	**-4.30**	**0.01**	0.62	0.49	**5.27**	**0.01**
No safe water	0.37	0.72	**3.95**	**0.02**	-1.30	0.15	**-3.20**	**<0.01**
No improved latrine	-0.70	0.49	**-9.00**	**<0.01**	**-1.70**	**0.08**	**-3.40**	**<0.01**
No shoes	-0.30	0.73	-2.70	0.28	-0.90	0.28	**-2.80**	**<0.01**

Effect modification was jointly assessed, age, economic quintile, mother living and education level, baseline aggregate worm burden. Heirarchical principal was maintainedby including interacted coavriates intervention group and the individual household WASH covariate. Interactions significant at p<0.1 are shown in bold.

Table 6-9: Multivariable models of the impact between intervention and control for household and WASH-level covariates

		Ascaris lumbricoides						Hookworm					
		Prevalence			Intensity of infection			Prevalence			Intensity of infection		
		OR	(95% CI)	*p*	IRR	(95% CI)	*p*	OR	(95% CI)	*p*	IRR	(95% CI)	*p*
***Girls* (n=561)**													
Handwashing station	Yes	0.85	0.29-2.44	0.75	1.62	0.07-36.90	0.76	3.18	0.79-12.80	0.10	39.98	2.51-636.00	0.01
	No	**0.17**	**0.06-0.47**	**<0.01**	**0.00**	**8.05-0.00**	**<0.01**	3.49	0.77-15.70	0.10	**17.83**	**1.09-291.00**	**0.04**
Safe water	Yes	0.61	0.26-1.41	0.24	**0.09**	**0.01-0.94**	**0.04**	3.31	0.76-14.40	0.11	**22.18**	**6.69-73.40**	**<0.01**
	No	**0.11**	**0.03-0.35**	**<0.01**	**0.00**	**4.69-0.01**	**<0.01**	3.45	0.88-13.40	0.07	**32.11**	**3.42-300.00**	**<0.01**
Improved latrine	Yes	0.25	0.05-1.42	0.12	0.05	0.00-1.22	0.07	16.88	1.00-285.00	0.05	416.25	9.31-1,859.00	<0.01
	No	**0.38**	**0.17-0.87**	**0.02**	**0.00**	**0.00-0.03**	**<0.01**	1.50	0.45-5.05	0.50	6.26	1.39-28.00	0.02
Shoes	Yes	**0.23**	**0.09-0.57**	**<0.01**	**0.00**	**0.00-0.02**	**<0.01**	**4.44**	**0.92-21.40**	**0.06**	**82.39**	**15.50-437.00**	**<0.01**
	No	0.85	0.26-2.77	0.78	0.15	0.00-7.87	0.34	2.01	0.50-8.06	0.31	1.90	0.34-10.50	0.46
Geophagy	Yes	**0.39**	**0.17-0.92**	**0.03**				**3.61**	**1.01-12.90**	**0.05**			
	No	0.16	0.02-1.12	0.06				2.39	0.32-17.70	0.38			
Boys (n=499)													
Handwashing station	Yes	0.41	0.06-2.61	0.34	2.77	0.21-36.20	0.43	1.54	0.38-6.26	0.54	0.03	0.00-1.19	0.06
	No	1.24	0.45-3.45	0.67	0.10	0.01-1.09	0.06	2.43	0.64-9.29	0.19	**4.20**	**1.23-14.20**	**0.02**
Safe water	Yes	0.61	0.17-2.25	0.45	0.08	0.00-1.62	0.10	2.86	0.67-12.10	0.15	0.82	0.07-9.93	0.88
	No	1.12	0.28-4.53	0.87	3.01	0.32-28.10	0.33	1.00	0.34-2.94	1.00	**0.12**	**0.02-0.88**	**0.04**
Improved latrine	Yes	1.23	0.18-8.49	0.83	**148.04**	**5.02-4,359.00**	**<0.01**	6.54	0.93-45.80	0.06	4.38	0.19-103.00	0.35
	No	0.60	0.22-1.61	0.30	**0.01**	**0.00-0.20**	**<0.01**	1.10	0.41-3.00	0.84	**0.14**	**0.03-0.74**	**0.02**
Shoes	Yes	0.96	0.07-12.40	0.98	1.07	0.01-78.60	0.98	9.61	0.84-109.00	0.07	**30.43**	**3.95-234.00**	**<0.01**
	No	0.55	0.13-2.34	0.41	**0.04**	**0.00-0.81**	**0.04**	1.22	0.41-3.67	0.71	0.09	0.01-1.44	0.09

Estimates of effect calculated using a linear combination of mean prevalence of WASH covariate, stratified by gender. Estimates adjusted by age, baselineline worm level, economic status, mother alive and education level, and all other interaction terms and their covariates

6.6 References

Al-Mekhlafi, H. M., J. Surin, et al. (2008). "Pattern and predictors of soil-transmitted helminth reinfection among aboriginal schoolchildren in rural Peninsular Malaysia." Acta Trop **107**(2): 200-204.

Anderson, R. M. and R. M. May (1991). Infectious Diseases of Humans. Oxford, U.K., Oxford University Press.

Anderson, R. M. and G. A. Schad (1985). "Hookworm burdens and faecal egg counts: an analysis of the biological basis of variation." Transactions of the Royal Society of Tropical Medicine & Hygiene **79**(6): 812-825.

Barreto, M. L., B. Genser, et al. (2010). "Impact of a citywide sanitation program in Northeast Brazil on intestinal parasites infection in young children." Environ Health Perspect **118**(11): 1637-1642.

Bethony, J., S. Brooker, et al. (2006). "Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm." Lancet **367**(9521): 1521-1532.

Brooker, S. and D. A. P. Bundy (2008). Soil-transmitted helminths (geohelminths). Manson's Tropical Diseases. G. C. Cook, Zumla, A.I. . London, Elsevier: 1515–1548.

Brooker, S., N. B. Kabatereine, et al. (2009). "An updated atlas of human helminth infections: the example of East Africa." Int J Health Geogr **8**: 42.

Cairncross, S., U. Blumenthal, et al. (1996). "The public and domestic domains in the transmission of disease." Trop Med Int Health **1**(1): 27-34.

Chan, M. S., G. F. Medley, et al. (1994). "The evaluation of potential global morbidity attributable to intestinal nematode infections." Parasitology **109 (Pt 3)**: 373-387.

Crompton, D. W. (1999). "How much human helminthiasis is there in the world?" Journal of Parasitology **85**: 397-403.

Eisenberg, J. N., J. C. Scott, et al. (2007). "Integrating disease control strategies: balancing water sanitation and hygiene interventions to reduce diarrheal disease burden." Am J Public Health **97**(5): 846-852.

Elkins, D. B., M. Haswell-Elkins, et al. (1988). "The importance of host age and sex to patterns of reinfection with Ascaris lumbricoides following mass anthelmintic treatment in a South Indian fishing community." Parasitology **96 (Pt 1)**: 171-184.

Filmer, D. and L. H. Pritchett (2001). "Estimating wealth effects without expenditure data--or tears: an application to educational enrollments in states of India." Demography **38**: 115-132.

Freeman, M., T. Clasen, et al. (2011). The impact of a school-based hygiene, water treatment, and sanitation intervention on reinfection with soil transmitted helminths in western Kenya: a cluster-randomized trial. London, London School of Hygiene and Tropical Medicine.

Freeman, M., L. Greene, et al. (2011). A cluster-randomized trial assessing the impact of a school-based water treatment, hygiene, and sanitation program on pupil absence in Nyanza Province, Kenya.

Gulani, A., J. Nagpal, et al. (2007). "Effect of administration of intestinal anthelmintic drugs on haemoglobin: systematic review of randomised controlled trials." BMJ **334**(7603): 1095.

Gunawardena, G. S., N. D. Karunaweera, et al. (2005). "Effects of climatic, socio-economic and behavioural factors on the transmission of hookworm (Necator americanus) on two low-country plantations in Sri Lanka." Ann Trop Med Parasitol **99**(6): 601-609.

Gwatkin, D. R., S. Rustein, et al. (2007). Socio-Economic Differences in Health, Nutrition, and Population: Kenya. Country Reports on HPN and Poverty. Washington, DC, The World Bank.

Hall, A., K. S. Anwar, et al. (1992). "Intensity of reinfection with Ascaris lumbricoides and its implications for parasite control." Lancet **339**(8804): 1253-1257.

Hall, A., L. N. Khanh, et al. (2001). "An association between chronic undernutrition and educational test scores in Vietnamese children." Eur J Clin Nutr **55**(9): 801-804.

Harhay, M. O., J. Horton, et al. (2011). "Diagnostics are central for a truly holistic approach against intestinal parasitic diseases." Int J Infect Dis **15**(2): e76-77.

Hayes, R., L. H. Moulton, et al. (2009). Cluster randomized controlled trials. New York, Chapman and Hall/CRC Press.

Hotez, P. J., D. A. P. Bundy, et al. (2006). Helminth Infections: Soil–Transmitted Helminth Infections and Schistosomiasis. Disease Control Priorities in Developing Countries (2nd Edition),ed. New York, Oxford University Press: 467-482.

Katz, N., A. Chavez, et al. (1972). "A simple device for quantitative stool thick-smear technique in Schostosomiasis mansoni." Rev Inst Med Trop Sao Paulo **14**(6): 397-400.

Keiser, J. and J. Utzinger (2008). "Efficacy of current drugs against soil-transmitted helminth infections: systematic review and meta-analysis." JAMA **299**(16): 1937-1948.

Killewo, J. Z., S. Cairncross, et al. (1991). "Patterns of hookworm and Ascaris infection in Dar es Salaam." Acta Trop **48**(3): 247-249.

Kleinbaum, D. G. and M. Klein (2002). Logistic Regression: A Self-Learning Text, Springer.

Knopp, S., K. A. Mohammed, et al. (2010). "Patterns and risk factors of helminthiasis and anemia in a rural and a peri-urban community in Zanzibar, in the context of helminth control programs." PLoS Negl Trop Dis **4**(5): e681.

Luoba, A. I., P. Wenzel Geissler, et al. (2005). "Earth-eating and reinfection with intestinal helminths among pregnant and lactating women in western Kenya." Tropical Medicine & International Health **10**(3): 220-227.

Mascarini-Serra, L. M., C. A. Telles, et al. (2010). "Reductions in the prevalence and incidence of geohelminth infections following a city-wide sanitation program in a Brazilian Urban Centre." PLoS Negl Trop Dis **4**(2): e588.

Moraes, L. R., J. A. Cancio, et al. (2004). "Impact of drainage and sewerage on intestinal nematode infections in poor urban areas in Salvador, Brazil." Trans R Soc Trop Med Hyg **98**(4): 197-204.

Moraes, L. R. S. and C. Cairncross (2004). "Environmental interventions and the pattern of geohelminth infections in Salvador, Brazil." Parasitology **129**: 223-232.

Murray, C. and A. Lopez (1996). The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. Global Burden of Disease and Injury Series Vol. 1 xxxii, 990 p. Boston, Massachusetts, School of Public Health, Harvard University.

Olsen, A., H. Samuelsen, et al. (2001). "A study of risk factors for intestinal helminth infections using epidemiological and anthropological approaches." J Biosoc Sci **33**(4): 569-584.

Peter J. Hotez, Donald A. P. Bundy, et al. (2006). Helminth Infections: Soil–Transmitted Helminth Infections and Schistosomiasis. Disease Control Priorities in Developing Countries New York, Oxford University Press: 467-482

Pullan, R. L., P. W. Gething, et al. (2011). "Spatial modelling of soil-transmitted helminth infections in Kenya: a disease control planning tool." PLoS Negl Trop Dis **5**(2): e958.

Smith, J. L. and S. Brooker (2010). "Impact of hookworm infection and deworming on anaemia in non-pregnant populations: a systematic review." Trop Med Int Health **15**(7): 776-795.

Stothard, J. R., E. Imison, et al. (2008). "Soil-transmitted helminthiasis among mothers and their pre-school children on Unguja Island, Zanzibar with emphasis upon ascariasis." Parasitology **135**(12): 1447-1455.

Sur, D., D. R. Saha, et al. (2005). "Periodic deworming with albendazole and its impact on growth status and diarrhoeal incidence among children in an urban slum of India." Transactions of the Royal Society of Tropical Medicine & Hygiene **99**(4): 261-267.

Taylor-Robinson, D. C., A. P. Jones, et al. (2007). "Deworming drugs for treating soil-transmitted intestinal worms in children: effects on growth and school performance." Cochrane Database Syst Rev(4): CD000371.

Traub, R. J., I. D. Robertson, et al. (2004). "The prevalence, intensities and risk factors associated with geohelminth infection in tea-growing communities of Assam, India." Trop Med Int Health **9**(6): 688-701.

Ugbomoiko, U. S., V. Dalumo, et al. (2009). "Socio-environmental factors and ascariasis infection among school-aged children in Ilobu, Osun State, Nigeria." Transactions of the Royal Society of Tropical Medicine & Hygiene **103**(3): 223-228.

Vyas, S. and L. Kumaranayake (2006). "Constructing socio-economic status indices: how to use principal components analysis." Health Policy Plan **21**(6): 459-468.

WHO (2002). World health report: annex table 2: deaths by cause, sex, and mortality stratum in WHO regions and annex table 3: burden of disease in DALYs by cause, sex and mortality stratum in WHO regions. Geneva, World Health Organization: 186-193.

WHO (2004). Prevention and control of schistosomiasis and soil transmitted helminthiasis. Geneva, World Health Organization.

WHO and UNICEF (2010). Progress on Sanitation and Drinking-water: 2010 Update. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. Geneva.

Wordemann, M., K. Polman, et al. (2006). "Prevalence and risk factors of intestinal parasites in Cuban children." Trop Med Int Health **11**(12): 1813-1820.

7. Assessing the impact of a school-based water treatment, hygiene, and sanitation program on pupil diarrhea: A cluster-randomized trial

Journal: *TBD*

Authorship order: *Matthew C. Freeman, Thomas Clasen, Richard Rheingans, and others TBD*

Stage of publication: *Not yet submitted*

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper:

I co-wrote the research proposal and study design, and led field data collection, data cleaning, and executed all analyses. I wrote all drafts of the paper.

Candidate's signature

Supervisor or senior author's signature to confirm role as stated above

7.1 Abstract

We conducted a cluster-randomized trial to assess the impact of a school-based water supply, water quality, sanitation, and hygiene promotion intervention on diarrhoeal disease among primary school pupils. The study was carried out among 4,665 pupils in 185 public primary schools in Nyanza Province, Kenya. Two study populations were used: schools with a dry season water source within 1KM and those without. Of schools with water nearby, pupils in schools that received a hygiene promotion and water treatment (HP&WT) and sanitation improvement showed no difference in period prevalence (RR 0.88, 95% CI 0.60-1.28) or duration of illness (IRR 0.85, 95% CI 0.57-1.24) compared to controls. Those that received only the HP&WT showed similar results. Schools without a water source in the dry season that received a water supply improvement, followed by HP&WT and sanitation showed a 66% reduction in diarrhoeal disease (RR 0.34, 95% CI 0.17-0.64) and days of illness (IRR 0.30, 95% CI 0.15-0.60). There were no differences in results by gender.

7.2 Introduction

Nearly 1.9 million children die each year from diarrhoeal diseases, accounting for 19% of the total child deaths and 6.3% of the global disease burden (Boschi-Pinto et al., 2008, Pruss-Ustun et al., 2008). Inadequate WASH are responsible for 88% of all diarrhoeal cases (Pruss-Ustun A and C, 2006). Of global risk factors, unsafe WASH ranks second in its contribution to disability

adjusted life years (DALYs), accounting for over 53 million DALYs, 6.3% of the global disease burden (World Health Organisation, 2009a).

There is robust evidence of the health impact of household WASH conditions from community-based research (Esrey and Habicht, 1986, Fewtrell and Colford, 2004, Rabie and Curtis, 2006, Curtis and Cairncross, 2003, Clasen et al., 2010, Clasen et al., 2007). However, few studies have addressed the impact of school-level WASH conditions, despite increased interest in the WASH sector to focus on improving access in schools (UNICEF, 2010).

Two school-based study that assessed the impact of school WASH on diarrhoea was available in the peer-reviewed literature. Migele and colleagues (2007) measured the impact of a school water treatment and hand washing project on the incidence of clinic visits at school for diarrhoea in one private boarding school in Kenya. Researchers reported a 36% drop in local clinic visits for diarrhoea-related symptoms following implementation of the intervention, as compared to the previous year. However, no statistical tests of association were presented and the sample size was one school. There were a number of challenges with the research design, including the small sample size and the lack of a control group. Because of this, the ability to attribute the impact to the intervention cannot be properly established.

A second study assessing the impact of school-based WASH improvements - by Wei (1998) and colleagues - addressed the effect of school-based interventions on reduction of diarrhoeal diseases. Wei found that a comprehensive schools-based WASH intervention reduced diarrhoea among

primary and secondary school children by 80%. However, the study was only conducted in two schools, analysis procedures could not be verified, and, as such, results should be interpreted with caution.

Schools are places for children to learn in both formal and informal ways. At school, children will congregate in social groups, practice learned behavior, develop and codify social norms, and try to conform (Sidibe, 2007). WASH access at school is a critical element of a healthy school environment: it can mitigate disease burden, impact students in ways beyond health, influence the community outside of the school, and reach vulnerable populations (Onyango-Ouma et al., 2005, Pearson and McPhedran, 2008). WASH improvements in turn may lead to improved school attendance and educational attainment, especially for girls (World Health Organisation, 2009b).

This study used a cluster-randomized trial in Kenya primary schools to assess the effect of improving school WASH conditions on pupil diarrhoea. Our outcomes of interest were period prevalence of diarrhoea and duration of illness.

7.3 Methods

7.3.1 Setting

The study was conducted in the context of a five-year applied research program assessing the health impact, educational impact, knowledge diffusion, and sustainability of a school-based WASH program. CARE, an international non-governmental organization with considerable experience

implementing WASH programs in Nyanza Province, Kenya, led the program. Researchers were engaged to establish the experimental design of the evaluation, but did not have considerable influence over the contents of the intervention. Implementing partners included CARE, Water.org, Kenya Water and Health Organization, and Sustainable Aid in Africa. The study was conducted in three geographically contiguous strata, which encompassed eight administrative divisions in four districts.

7.3.2 School eligibility

The study was conducted in Nyanza Province, Kenya between January 2007 and November 2008. The study included 185 schools, divided into two study groups: 1) water "available" schools with a dry season water source with one kilometer, and 2) water "available" schools with no improved source within two kilometers or any source during the dry season within one kilometer (WHO and UNICEF, 2010). Criteria for water availability were established by CARE based on previous experience, and with input from Government of Kenya Ministry of Water. Schools were only eligible for either study group if they exceeded the Government of Kenya pupil to latrine ratio of 30:1 for boys and 25:1 for girls (Republic of Kenya Ministry of Education, 2008).

7.3.3 Study design

Schools in the water "available" group were eligible to be allocated into one of three intervention arms: 1) hygiene promotion and water treatment (HP&WT), which included teacher training on hygiene behavior change, containers for

safe drinking water storage, buckets with taps to be used for handwashing, and a one-year supply of WaterGuard (a liquid chlorine-based sodium hypochlorite solution used for point-of-use water treatment) (O'Reilly et al., 2008); 2) HP&WT with the addition of school latrines, which included up to seven ventilated improved pit latrines, depending on previous access relative to pupil to latrine ratios; or 3) a control. Schools in the water "scarce" schools were allocated into one of two study arms: 1) improvements to school water supply, with the subsequent improvements for HP&WT plus sanitation described above, or 2) control. Additional detail of the intervention packages are discussed elsewhere (Freeman et al., 2011b). Water supply improvements included either a drilled borehole at the school or community (with guaranteed access to the school), or 60 cubic meter rainwater harvesting tanks based on groundwater potential.

7.3.4 School selection and allocation

Schools were assessed for eligibility through the use of a rapid assessment of school WASH conducted in collaboration with the Kenya Ministry of Education. Of the 198 schools eligible for the water "available" research group, 135 were randomly selected and allocated equally into three study arms (Figure 1). Of the 91 schools eligible for the water "scarce" group, 50 were randomly assigned to intervention or control arms. School selection and allocation to intervention status were stratified by the three geographic strata for logistics and to maximize heterogeneity of wealth and water access. School eligibility and selection is discussed in detail elsewhere (Freeman et

al., 2011b).

7.3.4 Sample size

The sample size for this study was constrained by the number of schools, pupil surveys, and follow-up time points in the larger trial. We assumed a period prevalence of 10% in the control group and a design effect of 2. As such, within the water "available" group, with 25 pupils per cluster and 45 clusters per arm we are able to detect a 50% reduction in diarrhoea in the intervention group compared to the controls, at an $\alpha=0.05$ with a power of 80%. For the same parameters in the water "scarce" group, with 25 pupils per cluster and 25 clusters, we are able to detect a 67% reduction in diarrhoea.

7.3.5 Data collection

Data were collected at baseline (February-March 2007) and following implementation (September-October 2008). Facility surveys were conducted with head teachers to assess water conditions at the school. Aggregate household data – used to assess imbalance in the study population and as covariates in multivariable analysis – were collected as part of a separate protocol (Freeman et al., 2011b). As part of this analysis, household asset score was used to calculate a wealth index through principal component analysis (Vyas and Kumaranayake, 2006, Gwatkin et al., 2007).

Structured interviews with pupils were conducted in Duluo language by trained enumerators. The survey captured demographic indicators such as age, gender, grade, knowledge and attitudes regarding WASH practices, and

school WASH conditions. Period prevalence of diarrhoea was assessed using self-report for cases in the previous one week. Duration of diarrhoeal episodes was also calculated using self-report. The case definition of diarrhoea was 3 or more loose or watery stools over a 24-hour period (Baqui et al., 1991). Baseline data was not usable due to problems encountered with data collection devices; as such we rely on the randomization to control for baseline imbalances.

Various studies of caregiver recall bias for reported diarrhoea among young children have revealed under-estimates as recall period increases (Alam et al., 1989, Ramakrishnan et al., 1998, Byass and Hanlon, 1994, Feikin et al., 2010). Though recall periods of 2-3 days are typically used to assess diarrhoea, severe diarrhoea is not subject to the same level of recall bias (Zafar et al., 2010). Recall bias falls less sharply with self-reported diarrhoeal illness as compared to parent-reported measures and a recall period of 4 days in rural Kenya was recommended for precision instead of a two-week recall (Feikin et al., 2010).

Diarrhoea was a secondary outcome measure of the overall research study. Since we were constrained in the number of schools and follow-up time points available, we concluded that the improvement in power in using seven-day recall to detect a difference between the intervention and control was more important than the underestimation of less severe cases of diarrhoea. Though courtesy bias may still exist, a problem with all self-reported measures, we do not have reason to believe that recall bias would not be

similar between intervention and control groups. Moreover, the bias will be towards the null.

Data were collected using digital handheld devices and entered into Microsoft Access 2003. Ethical clearance was obtained by Emory University, Great Lakes University of Kisumu, London School of Hygiene and Tropical Medicine, and the Kenyan Ministries of Health, Education, and Water. Teachers consented for pupils *en loco parentis* prior to participation in the study.

7.3.6 Data analysis

Data were cleaned in SAS version 9.3 (Cary, NC, and analyzed in STATA version 11 (College Station, TX). To compare imbalance at baseline in the absence of a baseline measure of effect, we assessed various school and aggregate household characteristics and report either n(%) or cluster-level means and standard deviations. For basic statistics showing period prevalence of diarrhoea, *p* values calculated using generalized linear models, using a binary distribution with a log link. For days of diarrhoea, we calculated the number of days of reported diarrhoea over the total days in the reporting period per 100 pupil days.

To estimate the effect of the intervention on diarrhoea, we first tested for interaction with geographic strata. Since none was found, we present models controlling only for geographic strata (Model 1) and models with *a priori* determined covariates (Model 2). These covariates included school and

aggregated community characteristics at baseline (Freeman et al., 2011b). Some covariates were missing in up to five schools. As a result, mean values calculated by geographic strata were imputed for these covariates. The resulting effect estimates and standard errors were nearly identical to those without imputed values.

Effect estimates were assessed overall and stratified by gender. Models assessing diarrhoea period prevalence report risk ratios using GLM models as discussed above. Days of diarrhoea were analyzed using poisson regression (Colford et al., 2002). All models were calculated using the *svy* command in STATA, and accounted for clustering at the school level, pupil selection weights, and stratification.

7.4 Results

7.4.1 Baseline school and community characteristics

School and community characteristics at baseline are found in Table 1. For schools in the water "available" group, control schools were similar to control schools for most assessed characteristics; though they were smaller and had fewer schools with cement floors. Characteristics for water "available" schools were also similar for assessed characteristics.

7.4.2 Unadjusted estimates of diarrhoea prevalence

We interviewed 4,655 pupils from 185 public primary schools, resulting in 32,585 pupil days. Diarrhoea was reported by 68 (6.0%) of pupils in the water

"available" control schools (Table 2). This was not statistically different than for pupils in schools in the HP&WT group (p=0.95) or HP&WT plus sanitation group (p=0.81). Similar values were found when the results were stratified by gender. Among the water "scarce" group, pupils attending schools that received water supply, HP&WT, and sanitation, 23 (3.6%) reported period prevalence of diarrhoea compared to 54 (5.7%) in the control (p=0.004). Statistically lower period prevalence of diarrhoea were reported for both girls (p=0.03) and boys (p=0.01) in the intervention schools compared to those in the control.

Within the water "available" group, those that received HP&WT reported 2.1 days of diarrhoea per 100 pupil days compared to 2.2 (p=0.86) in the controls. Students in schools that received sanitation reported 2.0 days, which was also not statistically different from the controls (p=0.78). In the water "scarce" schools, pupils in the intervention arm reported 1.3 days per 100 pupil-days, compared to 2.9 days in the control (p=0.01).

7.4.3 Adjusted estimates of diarrhoea prevalence and days of illness

For the schools in the water "available group," a model controlling for geographic strata showed no effect of the HP&WT intervention on reducing diarrhoea (risk ratio [RR] 1.00, 95% confidence interval [CI] 0.70 – 1.43) or the HP&WT with the addition of sanitation compared to the control (RR 0.95, CI 0.67-1.35) (Model 1, Table 3). The full model, controlling for all covariates similarly did not show a reduction in diarrhoea for either the HP&WT group (RR 0.87, CI 0.62-1.21) or the HP&WT group versus the control (Model 2).

When the models were stratified by gender, no significant effects were found. The effect of HP&WT on reducing diarrhoea among girls was suggestive of an effect, though the finding was not statistically significant (RR 0.63, CI 0.36-1.09).

The findings were similar when children attending schools in the water "available" group were assessed for days of illness (Table 4). For full models, HP&WT schools showed no effect of the intervention (incidence rate ratio [IRR] 0.86, CI 0.58-1.27); similar results were found for schools that received HP&WT and sanitation (IRR 0.85, CI 0.57-1.24). The gender-stratified findings were similar to those of diarrhoea period prevalence. The covariate model for girls showed a suggestive, though non-significant effect of the HP&WT intervention compared to controls (IRR 0.56, CI 0.29-1.05).

For water "scarce" schools that received water supply, HP&WT, and sanitation, there was a large and statistically significant overall reduction in diarrhoea period prevalence (RR 0.34, CI 0.17-0.64) (Table 5). The effect remained significant for girls (RR 0.37, CI 0.16-0.84) and boys (RR 0.26, CI 0.13-0.54). For days of illness, covariate models showed significant reductions in days of diarrhoea (IRR 0.30, CI 0.15-0.60) overall, and stratified by girls (IRR 0.33, CI 0.15-0.72) and boys (IRR 0.25, CI 0.10-0.60) (Table 6).

7.5 Discussion

We found strong evidence among schools in the water "scare" group that provision of a comprehensive school-based WASH intervention was effective

in reducing the risk of diarrhoeal diseases. The 66% reduction overall was similar to the protection accorded both boys and girls. On the other hand, we found no evidence that the interventions without water supply improvements reduced diarrhoea.

The finding that school-WASH can be protective against diarrhoea is consistent with the only known studies to have investigated this outcome from environmental interventions in schools. Migele (2007) found similar reductions in diarrhoea risk, though the intervention focused on water treatment and handwashing with soap in a boarding school. Wei (1998) reported a diarrhoea reduction of 80% for a sanitation intervention in China. Our findings are also consistent with meta-analyses that assess water supply, water treatment, sanitation, and hygiene as part of combined interventions (Fewtrell et al., 2005). These meta-analyses have shown that combined interventions are not significantly different from interventions of individual WASH components, a finding not supported by our data (Esrey and Habicht, 1986, Curtis and Cairncross, 2003, Clasen et al., 2007).

We cannot rule out the possibility that the combined treatment effect of interventions that included water supply could be attributable to systematic bias from the intervention design. water "scarce" schools had poorer WASH access than those schools who had access to water. These schools were enrolled into the study because of that lack of water and the design of the study required that they receive water before other components of the intervention were added. While schools in the water "available" group

ostensibly had access to water, we know that in many cases, this access was intermittent and poor.

Due to the different criteria for selection into the different water "scarce" and "available" study groups, these interventions should not be compared to each other. It is likely the case that baseline characteristics play a substantial role in what interventions - water supply, water quality, hygiene, sanitation – result in reduced diarrhea. In households, drinking water is essential and a water supply improvement may increase the available quantity for hygiene and sanitation and quality by reducing transportation distance (Wright et al., 2004). However, schools without a water supply frequently have no water for their students for any purpose (Wright et al., 2004, Freeman et al., 2011b). It is conceivable that the water "available" schools did not benefit from the hygiene and sanitation improvement because they did not have sufficient water to optimally provide the requisite water to make the intervention effective.

7.5.1 Limitations

Subjective measurements of self-reported disease morbidity are problematic, regardless of the disease or symptom. Recall bias may influence the precision of our estimate (Schmidt et al., 2011). In a study from Nepal, researchers found that care-giver report of same-day diarrhoeal illness was poorly correlated with clinical diagnoses and under-estimated the clinical diagnoses (Katz et al., 1998). While understanding and accounting for the underestimation of disease burden is critical for extrapolating morbidity estimates for a population, in the context of our study design, we were

primarily interested in the difference in reported cases of diarrhoea between pupils in intervention and control groups. Thus, the key limitation for this measurement is not variations in individual definitions of a subjective measure like diarrhoea. Recall of 2-3 days is typical for diarrhoea studies, though studies have used longer durations (Colford et al., 2002, Payment et al., 1991).

There is the possibility that our reductions in diarrhoea were due to courtesy bias and that we are over reporting our effect (Schmidt and Cairncross, 2009). While objective measures of diarrhoea are currently being explored, they are costly and not widely used as of now (Schmidt et al., 2010, Humphrey, 2009).

Data collection at a single time point and the lack of a viable baseline is a limitation of this study. However, while certain illnesses do require a baseline to validate imbalance, a cross-sectional measure of diarrhoea is not highly correlated with follow-up incidence. Accordingly, a baseline is not necessary to either increase precision of the estimate or adjust for the final analysis (Schmidt et al., 2011).

Finally, this study took place within the context of a broader research study. The intervention, specifically regarding sanitation improvements, had sub-optimal uptake, which may have biased our results to the null (Freeman et al., 2011b). The study was also conducted in the context of a broad-based deworming campaign. Our data show no correlation between reported diarrhoeal illness and STH infection, but given the effect of deworming on other health measurers, the effect of altering the rates of diarrhoea cannot be

ruled out (Freeman, unpublished data). However, given that the diarrhoea measurements were taken eight months following deworming and the expected return to baseline levels, we expect any potential effect to be minimal. This effect is likely insufficient sufficient to explain the differences in diarrhoeal morbidity found in the water "scarce" schools; however, it may have biased the effect in the water "available" schools towards the null. Regardless, all findings must be taken in the context of this deworming intervention.

7.5.2 Conclusion

The focus on the health effects of household-based WASH access is largely due to the morbidity and mortality associated with severe illness and potential for stunting among that population (Fink et al., 2011, Weisz et al., 2011). In addition, the millennium development goals focus on WASH access at home, but do not mention access at school, though conditions in the world's schools are quite dire (UNICEF, 2010). Our findings support the assertion that improving school WASH can help mitigate the disease burden, especially when corroborated with findings that improved school WASH can reduce absence and soil-transmitted helminth reinfection (Freeman et al., 2011a, Freeman et al., 2011b).

7.6 Figures and Tables

Figure 7-1: Flow chart of school selection

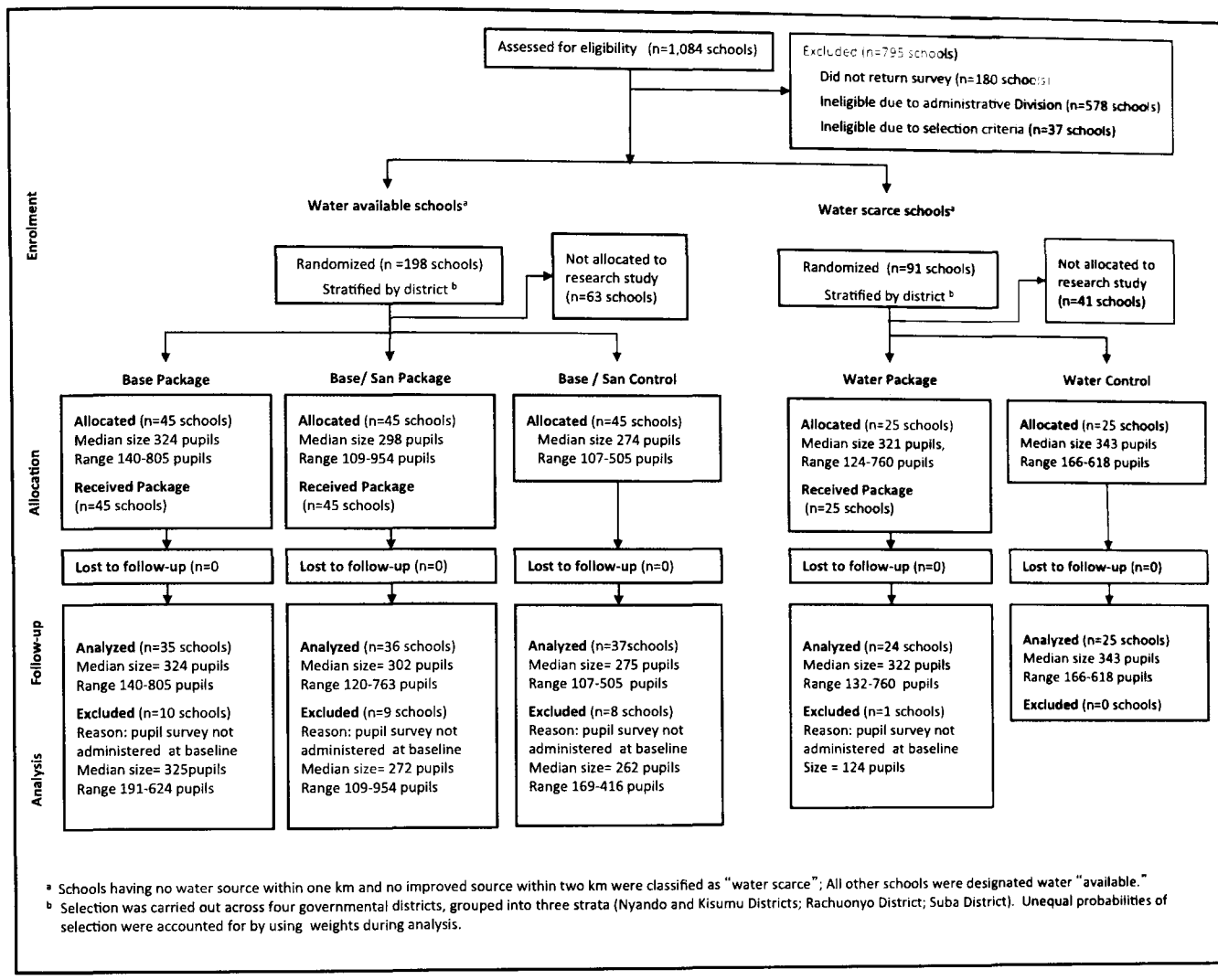


Table 7-1: School conditions and household characteristics at baseline for all intervention groups: hygiene promotion and water treatment (HP&WT); HP&WT and sanitation; water supply, HP&WT, and sanitation; and their respective controls

	Water "available"			Water "scarce"	
Variable	**Control**	**HP&WT**	**HP&WT + sanitation**	**Control**	**water supply HP&WT + sanitation**
School conditions	*n=44*	*n=45*	*n=44*	*n=25*	*n=24*
School enrollment in number of pupils	274 (83)	355 (143)	344 (182)	370 (125)	332 (142)
Pupils per teacher	28 (7)	33 (10)	33 (12)	36 (12)	32 (10)
Proportion of girls enrolled	48(4)	48 (3)	48(4)	48 (4)	48 (3)
Electricity at school	0 (0%)	2 (4%)	2 (4%)	0 (0%)	1 (4%)
Iron sheet roofing throughout school	43 (98%)	45 (100%)	43 (98%)	25 (100%)	24 (98%)
Cement floor throughout school	5 (11%)	13 (29%)	10 (22%)	8 (32%)	6 (25%)
School current water source is improved[†]	18 (41%)	20 (45%)	13 (30%)	13 (52%)	11 (46%)
Distance to school current water source in meters	117 (215)	148 (330)	184 (489)	109 (400)	251 (866)
School dry season water source is improved[†]	16 (36%)	11 (24%)	13 (30%)	2 (8%)	4 (17%)
Distance to school dry season water source in meters	1015 (1307)	1191 (1322)	865 (964)	2418 (1779)	2100 (1502)
Pupils per latrine	61 (44)	61 (30)	77 (61)	70 (41)	66 (35)
Boys per latrine	57 (38)	67 (36)	82 (58)	76 (61)	74 (42)
Girls per latrine	57 (40)	60 (32)	78 (68)	58 (35)	63 (36)
Household demographics[§]	*n=45*	*n=45*	*n=45*	*n=25*	n=25
Female-headed households	29 (16)	30 (17)	33 (17)	29 (11)	33 (14)
Female head of household completed primary school	46 (16)	48 (18)	46 (18)	43 (13)	49 (16)
Distance to school from home in minutes	18 (6)	19 (9)	18 (6)	18 (6)	20 (6)
Household respondent used soap during handwashing demonstration	68 (20)	72 (15)	70 (19)	67 (12)	70 (19)
Household currently using improved drinking water source[†]	66 (32)	64 (31)	64 (30)	69 (30)	60 (32)
Latrine coverage in community[#]	38 (21)	38 (22)	39 (23)	41 (27)	43 (23)
Percent households in poorest wealth quintile	23 (14)	19 (13)	23 (15)	17 (11)	16 (12)
Percent households in least poor wealth quintile	15 (11)	22 (15)	17 (18)	20 (14)	27 (19)

Data are means (SD) or numbers (%). [§]Mean and (standard deviation) calculated from cluster-level means or proportions. [†]Improved sources include boreholes, rainwater harvesting tanks, protected springs, and protected wells. [#]Improved latrine coverage are latrines within compound or home. Definitions found in WHO and UNICEF, 2010

Table 7-2: Period prevalence of diarrhea (and %) by study group and intervention arm (n=4,655) and for girls (n=2,240) and boys (n=2,415)

	Water "available"					Water "scarce"		
	Control	**HP&WT**	***p***	**HP&WT +San**	***p***	**Control**	**Water supply, HP&WT+San**	**p**
	n=1,127	*n=1,156*		*n=1,134*		*n=606*	*n=632*	
Period prevalence	68 (6.0)	62 (5.4)	0.95	65 (5.7)	0.81	54 (8.9)	23 (3.6)	0.004
By gender								
Girls	38 (7.1)	28 (5.1)	0.332	36 (6.4)	0.73	27 (9.4)	10 (3.3)	0.03
Boys	30 (5.1)	34 (5.6)	0.48	29 (5.1)	0.98	27 (8.5)	13 (4.0)	0.01
Days of diarrhea	2.2 (9.8)	2.1 (9.6)	0.86	2.0 (9.7)	0.78	2.9 (10.8)	1.3 (7.4)	0.01
By gender								
Girls	2.6 (10.4)	1.8 (8.8)	0.55	2.2 (9.5)	0.88	3.4 (12.6)	1.1 (6.8)	0.02
Boys	1.9 (9.1)	2.2 (10.4)	0.26	1.9 (9.7)	0.76	2.5 (8.9)	1.5 (8.0)	0.09

p values calcluated using unajusted generalized linear models accounting for study design, including clustering and pupil selection weights. "HP&WT" is hygiene promotion and water treatment, "San" is sanitation

Table 7-3: Model of pupil-reported diarrhea for schools that received hygiene promotion water treatment (HP&WT), sanitation (San) vs. control schools overall and stratified by gender

	Model 1 (n=3394)			Model 2 (n=3394)			Model 2 : Girls (n=1640)			Model 2 : Boys (n=1754)		
Variable	**RR**	**95% CI**	**p**	**RR**	**95% CI**	**p**	**RR**	**95% CI**	**p**	**RR**	**95% CI**	**p**
Intervention: HP&WT vs. control	1.00	0.70-1.43	0.99	0.87	0.62-1.21	0.41	0.63	0.36-1.09	0.10	1.20	0.74-1.94	0.47
Intervention: HP&WT + Sanitation vs. control	0.95	0.67-1.35	0.79	0.88	0.60-1.28	0.51	0.91	0.52-1.60	0.75	0.85	0.50-1.42	0.53
Geographic strata: Rachuonyo vs. Nyando	5.33	3.14-9.03	<0.001	5.96	3.42-10.30	<0.001	4.86	2.03-11.60	<0.001	7.93	3.52-17.80	<0.001
Geographic strata: Suba vs. Nyando	4.96	2.84-8.61	<0.001	5.20	2.92-9.23	<0.001	4.50	2.01-10.00	<0.001	6.42	2.59-15.90	<0.001
Grade				0.84	0.76-0.92	<0.001	0.76	0.68-0.85	<0.001	0.90	0.80-1.01	0.09
Gender: girls vs. boys				1.00	0.73-1.37	0.99						
Pupils per teacher				1.02	1.00-1.03	0.09	1.02	0.99-1.04	0.28	1.02	1.00-1.03	0.05
School has cement floors				0.77	0.51-1.15	0.20	0.58	0.33-1.03	0.07	0.90	0.53-1.52	0.68
Proportion of female headed household				1.03	0.40-2.63	0.95	2.54	0.73-8.85	0.14	0.37	0.11-1.29	0.12
Median time to school				0.99	0.96-1.01	0.30	0.98	0.94-1.02	0.42	0.98	0.95-1.01	0.39
Proportion of female head of household completed primary school				0.82	0.21-3.21	0.78	0.21	0.03-1.41	0.11	4.26	0.44-41.30	0.21
Proportion of female head of household that used soap at home				1.01	0.33-3.06	0.98	3.58	0.47-27.40	0.22	0.33	0.08-1.38	0.13
Proportion of household with protected water source				0.90	0.51-1.58	0.71	0.45	0.20-1.01	0.05	1.91	0.98-3.73	0.06
Proportion of household with latrine				0.65	0.23-1.85	0.42	0.31	0.05-1.86	0.20	0.94	0.27-3.24	0.92
Mean of latrine cleanliness score				0.87	0.69-1.10	0.24	0.95	0.68-1.31	0.75	0.76	0.56-1.03	0.08
Proportion of household in poorest SES quintile				2.37	0.76-7.38	0.14	1.22	0.21-6.92	0.82	6.32	1.17-34.00	0.03
Mean asset score				4.97	1.00-24.70	0.05	7.38	0.73-75.00	0.09	3.84	0.59-25.00	0.16
Percentage of school that are partial orphans				2.26	0.27-18.80	0.45	1.19	0.04-37.30	0.92	5.38	0.40-71.40	0.20

RR is risk ratio derrived from generalized linear modeling of reported period prevalence of diarrhea

Table 7-4: Model of pupil-reported days of diarrhea for schools that received hygiene promotion water treatment (HP&WT), sanitation (San) vs. control schools overall and stratified by gender

	Model 1 (n=3394)			Model 2 (n=3394)			Model 2 : Girls (n=1640)			Model 2 : Boys (n=1754)		
Variable	**IRR**	**95% CI**	**p**	**IRR**	**95% CI**	**p**	**IRR**	**95% CI**	**p**	**IRR**	**95% CI**	**p**
Intervention: HP&WT vs. control	1.03	0.67-1.60	0.88	0.86	0.58-1.27	0.44	0.56	0.29-1.05	0.07	1.31	0.76-2.26	0.33
Intervention: HP&WT + Sanitation vs. control	0.94	0.65-1.36	0.75	0.85	0.57-1.24	0.39	0.84	0.44-1.61	0.60	0.87	0.51-1.50	0.63
Geographic strata: Rachuonyo vs. Nyando	6.77	4.02-11.30	<0.001	7.36	4.06-13.30	<0.001	4.85	1.82-12.80	<0.01	11.85	4.93-28.40	<0.001
Geographic strata: Suba vs. Nyando	6.26	3.48-11.20	<0.001	6.39	3.37-12.00	<0.001	5.08	2.01-12.70	<0.01	8.27	3.13-21.80	<0.001
Grade				0.82	0.74-0.91	<0.001	0.75	0.67-0.84	<0.001	0.87	0.76-1.00	0.06
Gender: girls vs. boys				0.91	0.63-1.31	0.62						
Pupils per teacher				1.02	1.00-1.04	0.05	1.03	0.99-1.06	0.14	1.02	1.00-1.04	0.07
School has cement floors				0.80	0.47-1.36	0.40	0.63	0.30-1.32	0.23	0.83	0.46-1.51	0.55
Proportion of female headed household				0.81	0.29-2.31	0.70	1.86	0.45-7.75	0.39	0.35	0.09-1.31	0.12
Median time to school				0.98	0.96-1.01	0.30	0.98	0.93-1.02	0.36	0.99	0.95-1.02	0.50
Proportion of female head of household completed primary school				0.75	0.16-3.49	0.71	0.19	0.02-1.85	0.15	3.94	0.34-46.10	0.27
Proportion of female head of household that used soap at home				1.11	0.32-3.91	0.87	7.51	0.75-75.00	0.09	0.23	0.05-1.07	0.06
Proportion of household with protected water source				0.82	0.38-1.76	0.62	0.37	0.12-1.14	0.08	1.83	0.88-3.82	0.11
Proportion of household with latrine				0.54	0.18-1.65	0.28	0.21	0.03-1.61	0.13	0.96	0.27-3.40	0.95
Mean of latrine cleanliness score				0.86	0.68-1.09	0.21	0.93	0.66-1.32	0.69	0.77	0.56-1.06	0.12
Proportion of household in poorest SES quintile				1.89	0.50-7.10	0.34	0.69	0.07-7.38	0.76	6.05	1.12-32.50	0.04
Mean asset score				4.50	0.93-21.80	0.06	4.64	0.45-47.40	0.19	4.61	0.77-27.40	0.09
Percentage of school that are partial orphans				3.30	0.27-40.80	0.35	1.83	0.04-95.40	0.76	7.56	0.32-176.00	0.21

IRR is incidence rate ratio derrived from poisoon regression

Table 7-5: Model of pupil-reported diarrhea for schools that received hygiene promotion water treatment (HP&WT), sanitation (San) and water supply vs. control schools overall and stratified by gender

	Model 1 (n=1238)			Model 2 (n=1238)			Model 2 : Girls (n=596)			Model 2 : Boys (n=642)		
Variable	RR	95% CI	p	RR	95% CI	p	RR	95% CI	p	RR	95% CI	p
Intervention: Water supply, sanitation, HP&WT vs. control	0.39	0.22-0.69	<0.01	0.34	0.17-0.64	<0.01	0.43	0.17-1.05	0.07	0.26	0.13-0.54	<0.001
Geographic strata: Rachuonyo vs. Nyando	3.97	1.65-9.54	<0.01	5.41	1.76-16.50	<0.01	2.95	0.88-9.97	0.08	13.19	2.43-71.50	<0.01
Geographic strata: Suba vs. Nyando	2.34	0.95-5.76	0.07	4.53	1.27-15.90	0.02	3.11	0.72-13.30	0.12	8.84	1.27-61.30	0.03
Grade				0.72	0.63-0.83	<0.001	0.65	0.51-0.82	<0.01	0.77	0.63-0.95	0.02
Gender: girls vs. boys				0.84	0.54-1.30	0.42						
Pupils per teacher				1.00	0.98-1.02	0.99	1.01	0.98-1.05	0.43	0.99	0.97-1.01	0.57
School has cement floors				1.34	0.67-2.67	0.41	1.36	0.49-3.76	0.54	1.63	0.78-3.39	0.19
Proportion of female headed household				0.28	0.04-1.90	0.19	0.46	0.03-8.10	0.59	0.14	0.01-1.81	0.13
Median time to school				0.98	0.93-1.04	0.56	1.02	0.95-1.09	0.62	0.94	0.88-1.00	0.06
Proportion of female head of household completed primary school				11.41	1.34-97.00	0.03	18.66	0.36-966.00	0.14	8.15	0.38-174.00	0.18
Proportion of female head of household that used soap at home				1.38	0.28-6.70	0.68	1.60	0.26-9.95	0.61	1.26	0.15-10.80	0.83
Proportion of household with protected water source				1.60	0.80-3.21	0.18	2.12	0.52-8.68	0.29	1.48	0.57-3.85	0.41
Proportion of household with latrine				0.18	0.03-1.03	0.06	0.79	0.09-7.20	0.83	0.03	0.00-0.21	<0.01
Mean of latrine cleanliness score				0.78	0.59-1.01	0.06	0.99	0.62-1.58	0.96	0.61	0.40-0.93	0.02
Proportion of household in poorest SES quintile				1.30	0.12-14.60	0.83	0.45	0.01-15.30	0.65	9.16	0.24-343.00	0.23
Mean asset score				1.63	0.17-15.90	0.67	0.07	0.00-1.14	0.06	81.53	3.83-1,733.00	<0.01
Percentage of school that are partial orphans				0.89	0.05-15.00	0.93	3.57	0.02-511.00	0.61	0.18	0.01-2.89	0.22

RR is risk ratio derrived from generalized linear modeling of reported period prevalence of diarrhea

Table 7-6: Model of pupil-reported days of diarrhea for schools that received hygiene promotion water treatment (HP&WT), sanitation (San) and water supply vs. control schools overall and stratified by gender

	Model 1 (n=1238)			Model 2 (n=1238)			Model 2 : Girls (n=596)			Model 2 : Boys (n=642)		
Variable	IRR	95% CI	p	IRR	95% CI	p	IRR	95% CI	p	IRR	95% CI	p
Intervention: Water supply, sanitation, HP&WT vs. control	0.43	0.24-0.76	<0.01	0.30	0.15-0.60	<0.01	0.36	0.16-0.79	0.01	0.25	0.10-0.60	<0.01
Geographic strata: Rachuonyo vs. Nyando	3.66	1.02-13.10	0.05	6.43	2.20-18.70	<0.01	2.65	1.05-6.68	0.04	23.14	3.10-172.00	<0.01
Geographic strata: Suba vs. Nyando	2.32	0.64-8.49	0.20	8.09	2.45-26.60	<0.01	3.07	0.88-10.70	0.08	27.36	3.40-219.00	<0.01
Grade				0.71	0.63-0.80	<0.001	0.64	0.53-0.76	<0.001	0.78	0.64-0.96	0.02
Gender: girls vs. boys				0.87	0.57-1.33	0.52						
Pupils per teacher				1.01	0.99-1.03	0.39	1.00	0.97-1.03	0.97	1.02	0.99-1.04	0.25
School has cement floors				1.79	0.86-3.72	0.11	3.59	1.26-10.10	0.02	1.28	0.58-2.80	0.53
Proportion of female headed household				0.12	0.01-1.22	0.07	0.05	0.00-0.98	0.05	0.25	0.02-3.69	0.30
Median time to school				1.02	0.95-1.08	0.61	1.04	0.98-1.09	0.24	0.96	0.88-1.04	0.35
Proportion of female head of household completed primary school				60.60	5.01-732.00	<0.01	74.81	1.33-4,182.00	0.04	28.46	0.77-1,049.00	0.07
Proportion of female head of household that used soap at home				0.96	0.18-5.06	0.96	1.07	0.15-7.59	0.95	1.58	0.12-20.10	0.72
Proportion of household with protected water source				2.05	0.78-5.36	0.14	2.17	0.54-8.65	0.27	2.39	0.77-7.37	0.13
Proportion of household with latrine				0.28	0.04-2.21	0.22	0.27	0.02-3.86	0.33	0.08	0.01-0.91	0.04
Mean of latrine cleanliness score				0.68	0.48-0.95	0.03	0.96	0.63-1.45	0.84	0.50	0.31-0.83	<0.01
Proportion of household in poorest SES quintile				3.41	0.28-41.30	0.33	1.75	0.09-33.90	0.70	36.11	0.53-2,447.00	0.09
Mean asset score				1.67	0.15-18.60	0.67	0.06	0.00-0.86	0.04	271.95	6.24-1,184.00	<0.01
Percentage of school that are partial orphans				0.57	0.03-9.60	0.69	0.83	0.01-50.50	0.93	0.22	0.01-4.57	0.32

IRR is incidence rate ratio derrived from poisoon regression

7.7 References

ALAM, N., HENRY, F. J. & RAHAMAN, M. M. 1989. Reporting errors in one-week diarrhoea recall surveys: experience from a prospective study in rural Bangladesh. *Int J Epidemiol,* 18, 697-700.

BAQUI, A. H., BLACK, R. E., YUNUS, M., HOQUE, A. R., CHOWDHURY, H. R. & SACK, R. B. 1991. Methodological issues in diarrhoeal diseases epidemiology: definition of diarrhoeal episodes. *Int J Epidemiol,* 20, 1057-63.

BOSCHI-PINTO, C., VELEBIT, L. & SHIBUYA, K. 2008. Estimating child mortality due to diarrhoea in developing countries. *Bull World Health Organ,* 86, 710-7.

BYASS, P. & HANLON, P. W. 1994. Daily morbidity records: recall and reliability. *Int J Epidemiol,* 23, 757-63.

CLASEN, T., SCHMIDT, W. P., RABIE, T., ROBERTS, I. & CAIRNCROSS, S. 2007. Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *BMJ,* 334, 782.

CLASEN, T. F., BOSTOEN, K., SCHMIDT, W. P., BOISSON, S., FUNG, I. C., JENKINS, M. W., SCOTT, B., SUGDEN, S. & CAIRNCROSS, S. 2010. Interventions to improve disposal of human excreta for preventing diarrhoea. *Cochrane Database Syst Rev,* 6, CD007180.

COLFORD, J. M., JR., REES, J. R., WADE, T. J., KHALAKDINA, A., HILTON, J. F., ERGAS, I. J., BURNS, S., BENKER, A., MA, C., BOWEN, C., MILLS, D. C., VUGIA, D. J., JURANEK, D. D. & LEVY, D. A. 2002. Participant blinding and gastrointestinal illness in a randomized, controlled trial of an in-home drinking water intervention. *Emerg Infect Dis,* 8, 29-36.

CURTIS, V. & CAIRNCROSS, S. 2003. Effect of washing hands with soap on diarrhoea risk in the community: A systematic review. *The Lancet Infectious Diseases,* 3, 275-281.

ESREY, S. A. & HABICHT, J. P. 1986. Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiologic Reviews,* 8, 117-128.

FEIKIN, D. R., AUDI, A., OLACK, B., BIGOGO, G. M., POLYAK, C., BURKE, H., WILLIAMSON, J. & BREIMAN, R. F. 2010. Evaluation of the optimal recall period for disease symptoms in home-based morbidity surveillance in rural and urban Kenya. *Int J Epidemiol,* 39, 450-8.

FEWTRELL, L. & COLFORD, J. M. 2004. Water, Sanitation and Hygiene: Interventions and Diarrhoea, A Systematic Review and Meta-analysis. *In:* PREKER, A. S. (ed.) *Health, Nutrition and Population (HNP) Discussion Paper.* Washington, D.C.: The World Bank.

FEWTRELL, L., KAUFMANN, R. B., KAY, D., ENANORIA, W., HALLER, L. & COLFORD JR, J. M. 2005. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis. *The Lancet Infectious Diseases,* 5, 42-52.

FINK, G., GUNTHER, I. & HILL, K. 2011. The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986-2007. *Int J Epidemiol.*

FREEMAN, M., CLASEN, T., BROOKER, S., AKOKO, D. & RHEINGANS, R. 2011a. The impact of a school-based hygiene, water treatment, and sanitation intervention on reinfection with soil transmitted helminths in western Kenya: a cluster-randomized trial. London: London School of Hygiene and Tropical Medicine.

FREEMAN, M., GREENE, L., DREIBELBIS, R., SABOORI, S., MUGA, R., BRUMBACK, B. & RHEINGANS, R. 2011b. Assessing the impact of a school-based water treatment, hygiene, and sanitation program on pupil absence in Nyanza Province, Kenya: A cluster-randomized trial.

GWATKIN, D. R., RUSTEIN, S., JOHNSON, K., SULIMAN, E., WAGSTAFF, A. & AMOUZOU, A. 2007. Socio-Economic Differences in Health, Nutrition, and Population Within Developing Countries : AN OVERVIEW. *Country Reports on HNP and Poverty.* Washington, DC: Produced by the World Bank in collaboration with the Government of the Netherlands and the Swedish International Development Cooperation Agency.

HUMPHREY, J. H. 2009. Child undernutrition, tropical enteropathy, toilets, and handwashing. *Lancet,* 374, 1032-5.

KATZ, J., WEST, K. P., JR., LECLERQ, S. C., THAPA, M. D., KHATRY, S. K., SHRESTA, S. R., PRADHAN, E. K. & POHKREL, R. P. 1998. Agreement between clinical examination and parental morbidity histories for children in Nepal. *J Trop Pediatr,* 44, 225-9.

MIGELE, J., OMBEKI, S., AYALO, M., BIGGERSTAFF, M. & QUICK, R. E. 2007. Diarrhea prevention in a Kenyan school through the use of a simple safe water and hygiene intervention. *Am J Trop Med Hyg,* 76, 351-353.

O'REILLY, C., FREEMAN, M., RAVANI, M., MIGELE, J., A., M., AYALO, M., S., O., HOEKSTRA, M. R. & E., Q. R. 2008. The impact of a school-based safe water and hygiene programme on knowledge and practices

of students and their parents: Nyanza Province, western Kenya, 2006. *Epidemiology & Infection,* 136, 80-91.

ONYANGO-OUMA, W., AAGAARD-HANSEN, J. & JENSEN, B. B. 2005. The potential of schoolchildren as health change agents in rural western Kenya. *Soc Sci Med,* 61, 1711-1722.

PAYMENT, P., RICHARDSON, L., SIEMIATYCKI, J., DEWAR, R., EDWARDES, M. & FRANCO, E. 1991. A randomized trial to evaluate the risk of gastrointestinal disease due to consumption of drinking water meeting current microbiological standards. *Am J Public Health,* 81, 703-8.

PEARSON, J. & MCPHEDRAN, K. 2008. A literature review of the non-health impacts of sanitation. *Waterlines,* 27, 48-61.

PRUSS-USTUN A & C, C. 2006. Preventing disease through healthy environments – Towards an estimate of the environmental burden of disease. Geneva: World Health Organization.

PRUSS-USTUN, A., BONJOUR, S. & CORVALAN, C. 2008. The impact of the environment on health by country: a meta-synthesis. *Environ Health,* 7, 7.

RABIE, T. & CURTIS, V. 2006. Handwashing and risk of respiratory infections: a quantitative systematic review. *Trop Med Int Health,* 11, 258-67.

RAMAKRISHNAN, R., VENKATARAO, T., KOYA, P. K. & KAMARAJ, P. 1998. Influence of recall period on estimates of diarrhoea morbidity in infants in rural Tamil Nadu. *Indian J Public Health,* 42, 3-6.

REPUBLIC OF KENYA MINISTRY OF EDUCATION 2008. National School Water, Sanitation and Hygiene Promotion Strategy 2008-2015. Nairobi.

SCHMIDT, W. P., ARNOLD, B. F., BOISSON, S., GENSER, B., LUBY, S., BARRETO, I. C., CLASEN, T. & CAIRNCROSS, S. 2011. Epidemiological methods in diarrhoea studies – an update. *International Journal of Epidemiology,* in press.

SCHMIDT, W. P., BOISSON, S., GENSER, B., BARRETO, M. L., BAISLEY, K., FILTEAU, S. & CAIRNCROSS, S. 2010. Weight-for-age z-score as a proxy marker for diarrhoea in epidemiological studies. *J Epidemiol Community Health,* 64, 1074-9.

SCHMIDT, W. P. & CAIRNCROSS, S. 2009. Household water treatment in poor populations: is there enough evidence for scaling up now? *Environ Sci Technol,* 43, 986-92.

SIDIBE, M. A. 2007. Can hygiene be cool and fun? Understanding school children's motivations to use their school toilets and wash their hands with soap in Dakar, Senegal. DrPH.

UNICEF 2010. Raising Clean Hands: Advancing Learning, Health, and Participation through WASH in Schools.

VYAS, S. & KUMARANAYAKE, L. 2006. Constructing socio-economic status indices: how to use principal components analysis. *Health Policy Plan,* 21, 459-68.

WEI, X.-N., SHAO, B.-C., FANG, Z.-H., GAO, M. & ZHU, X.-L. 1998. Evaluation of the effects of prevention of diarrhoea and ascaris among students of health intervention measures in schools in rural areas. *China Journal of Public Health,* 14, 228.

WEISZ, A., MEULI, G., THAKWALAKWA, C., TREHAN, I., MALETA, K. & MANARY, M. 2011. The duration of diarrhea and fever is associated with growth faltering in rural Malawian children aged 6-18 months. *Nutr J,* 10, 25.

WHO & UNICEF 2010. Progress on Sanitation and Drinking-water: 2010 Update. *WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.* Geneva.

WORLD HEALTH ORGANISATION 2009a. Global Health Risks: Mortality and burden of disease attributable to selected major risks. Geneva: WHO.

WORLD HEALTH ORGANISATION 2009b. Water, Sanitation and Hygiene Standards for Schools in Low-cost Settings. *In:* JOHN ADAMS, JAMIE BARTRAM, YVES CHARTIER & SIMS, J. (eds.). Geneva: WHO.

WRIGHT, J., GUNDRY, S. & CONROY, R. 2004. Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Trop Med Int Health,* 9, 106-17.

ZAFAR, S. N., LUBY, S. P. & MENDOZA, C. 2010. Recall errors in a weekly survey of diarrhoea in Guatemala: determining the optimal length of recall. *Epidemiol Infect,* 138, 264-9.

8. Conclusion

This is the first study to comprehensively assess the impact of school-based improvements in WASH on the health and absenteeism of school children. It was conducted on a large scale among a vulnerable population. Unlike a research-driven efficacy study of an intervention delivered under controlled circumstances, the study was conducted as an evaluation of an actual intervention delivered programmatically under circumstances that could be implemented at scale. As a result, the results have strong external validity and should be of widespread interest in the WASH community.

The study allowed for the investigation of the most important WASH interventions using a rigorous randomized, controlled trial design—the gold standard for epidemiological evidence and causal inference. Our study was conducted from 2007-2009 in 185 schools assigned to two research groups based on availability of water. The study employed three separate intervention packages, which allowed for a limited discussion about the relative effect of, for example, HP&WT alone or with the addition of sanitation. However, we were not able to discuss the effect of a sanitation intervention only.

We found evidence of beneficial impacts from school-based WASH:

- Hygiene promotion and water treatment (HP&WT) alone and in concert with latrine improvements reduced school absence among girls;
- HP&WT with sanitation reduced *Ascaris lumbricoides* reinfection among girls

- HP&WT with sanitation reduced hookworm infection among boys; and
- A comprehensive WASH intervention that includes water supply reduced prevalence and total days of diarrhoea.

We also found strong evidence of interaction with household WASH conditions and shoe-wearing: children without improved access at home were more likely to benefit from the intervention.

These findings point to a potentially important role for school-based WASH in helping achieve widely recognized health and education goals for low-income countries. However, in many cases, the WASH interventions that we investigated were not protective against disease or absenteeism, or were protective only among one gender. Our findings suggest:

- HP&WT with or without sanitation improvements did not reduce absence for boys
- HP&WT and sanitation did not result in changes in *A. lumbricoides* reinfection for boys or hookworm for girls
- HP&WT with or without sanitation did not reduce diarrhoeal risk
- No reduction in the prevalence of anemia

We have already suggested some possible reasons for these mixed results. One is that the region experienced severe violence, loss of property, and internally displaced persons as a result of the post-election violence in the first few months of 2008. Schools in the study area were shut for four months and the project was disrupted. A second reason was sub-optimal uptake of the

intervention. Whether through poor delivery by the implementing partner, or poor participation by the recipient school and community, many schools did not reach pre-planned levels of WASH access. This may have underestimated the potential effect of improved school WASH access and biased our results to the null. Finally, the deworming that was conducted among all pupils in intervention and control group may have created a secular reduction in absence and diarrhoea that could have biased our results to the null.

It is possible that the real reasons why the effectiveness of school-based WASH to protect more generally against helminth infection, diarrhoeal disease and school absenteeism is because of patterns of exposure and transmission dynamics that are still not well characterized. Some of these issues can potentially be explored with additional analysis of the data generated in this study; others will be investigated in future studies of school-based WASH.

8.1 Further analysis of SWASH+ data

One of the key limitations to the findings presented, and to nearly all effectiveness field trials in global health, is the issue of sub-optimal interventions. While we report on the impact of our intervention on health and absence, we are only able to report on the impact based on what was actually available to the students. Some schools had successful interventions, while others did not. These issues are further complicated by the difficulty with accurately measuring handwashing behavior, difficulty in assessing latrine use, the context specific and complicated nature of assessing risk of drinking

water contamination, and until recently, the lack of a global standard for school WASH conditions (Ram et al., 2011, World Health Organisation, 2009, World Health Organisation, 2011, Clasen et al., 2010).

In order to address the issue of implementation heterogeneity, the SWASH+ team is developing new methods to assess the "treated of the treated." Given the complicated nature of compliance for a trial that has multiple components, we are focusing on provision of soap and safe water (detectible levels of chlorine). These methods draw from an instrumental variables approach to adjust for measured confounders (Cain et al., 2009). The methods will be developed to understand the role of successful implementation on absence reduction, and will be applied subsequently to an analysis of STH infection.

A second area for further investigation is regarding our finding that the construction of new latrines to schools did not reduce absence above those that received only hygiene promotion and water treatment (Chapter 4). As discussed, we believe, based on forthcoming data, this finding may have been due to poor latrine maintenance practices and availability of handwashing stations, even as more children used the latrines. In response, a second cluster-randomized trial is underway to determine if provision of low-cost latrine cleaning supplies, training, and monitoring of latrine conditions might lead to reduced absence among schools that already have been given latrines. The trial includes 60 schools, randomly allocated to three study arms that will receive 1) sufficient soap for handwashing only; 2) soap for handwashing and latrine cleaning, latrine maintenance supplies, and toilet

paper; and 3) controls. For this study, we are assessing if the interventions increased use and reduced absence. I am a co-author on the paper, which should be available within 2011.

An additional study is underway to further validate measures of absence. A pilot study was conducted to validate pupil-report of recall for absence. That study found that 95% of pupils correctly recalled missing school in the previous two weeks, as compared to the school registry data (Freeman, unpublished data). This study will report on additional analyses showing reported causes of absence, and correlation between reported absence, diarrhoea, STH infection. Additional work is underway in India by Freeman and Clasen as part of a separate project that seeks to further validate different measures of absence within a different study context.

8.2 Questions raised by this research

The research presented in this thesis, and SWASH+ in general, raise additional questions worth exploring. As SWASH+ was an effectiveness trial of a particular intervention at a particular time, researchers were not able to maximize the intervention in ways beyond what would normally be done in a development setting. The intervention was based on best practices from experience of the intervention partner. As such, similar studies in other geographic contexts need to be undertaken to validate, contract, and corroborate our findings. These studies could be explored elsewhere in sub-Saharan Africa or Asia, where disease burden and background access rates differ. Specifically, an additional study would be interesting in West Africa or

Muslim areas where access to sanitation at school requires water not only for handwashing, but anal cleansing.

In conjunction with additional studies to evaluate health and educational attainment, additional research is warranted on monitoring use and access to school WASH and a better understanding of sustained approaches. Our study reveals that even best practices are falling well short of providing minimal standards. Additional investment in the sector and improved process monitoring will help ensure that future studies are not reporting on sub-optimal interventions.

Integrated approaches, not just within WASH are key to better understanding the opportunities for improving pupil health. Our intervention improved water supply, water quality at the point of use, latrine access, and handwashing with soap, as well as issues around deworming. Yet, programs that provide additional components that require school WASH should be evaluated in concert with school WASH improvements. These interventions may include micronutrient supplementation, iron supplements, menstrual management, and school feeding programs. Additional studies should include these components to assess the complementarity and cost-effectiveness of these approaches.

Throughout the paper, I discuss the concept of "domestic" versus "public" disease transmission as developed by Cairncross and colleagues (Cairncross et al., 1996). Whether to prioritize mitigation of exposure at the public and domestic domains requires a more thorough understanding of background

illness rates, context specific diseases of importance, and local access to safe water, improved sanitation, and proper hygiene behavior. The role of household-based WASH to reduce diarrhoeal disease is well studied. Additional studies are warranted of when and how public – in this case school – transmission can be mitigated, either alone or in combination with interventions that intercede in both transmission pathways. Specifically, additional studies looking at household and school-level clustering of helminth infection and protozoa infection could help us better understand how sanitation and hygiene related diseases spread within a community.

Finally, while there has been an increase in investment in recent years, few data are available on global WASH in school coverage. Fundamental to the work of improving WASH access at school is the establishment of a global tracking system similar to the UNICEF/WHO Joint Monitoring Programme, which uses data collected from the Demographic and Health Surveys and Multiple Indicator Cluster Surveys. While the Millennium Development Goals track school enrollment, they do not establish goals for improving WASH access at school, nor is it tracked globally. Improving, and better understanding the health and educational implications of poor WASH in schools coverage can not be fully realized until we better understand where we currently are with regards to access.

8.3 References

CAIN, L. E., COLE, S. R., GREENLAND, S., BROWN, T. T., CHMIEL, J. S., KINGSLEY, L. & DETELS, R. 2009. Effect of highly active antiretroviral therapy on

incident AIDS using calendar period as an instrumental variable. *Am J Epidemiol,* 169, 1124-32.

CAIRNCROSS, S., BLUMENTHAL, U., KOLSKY, P., MORAES, L. & TAYEH, A. 1996. The public and domestic domains in the transmission of disease. *Trop Med Int Health,* 1, 27-34.

CLASEN, T. F., BOSTOEN, K., SCHMIDT, W. P., BOISSON, S., FUNG, I. C., JENKINS, M. W., SCOTT, B., SUGDEN, S. & CAIRNCROSS, S. 2010. Interventions to improve disposal of human excreta for preventing diarrhoea. *Cochrane Database Syst Rev,* 6, CD007180.

RAM, P. K., JAHID, I., HALDER, A. K., NYGREN, B., ISLAM, M. S., GRANGER, S. P., MOLYNEAUX, J. W. & LUBY, S. P. 2011. Variability in hand contamination based on serial measurements: implications for assessment of hand-cleansing behavior and disease risk. *Am J Trop Med Hyg,* 84, 510-6.

WORLD HEALTH ORGANISATION 2009. Water, Sanitation and Hygiene Standards for Schools in Low-cost Settings. *In:* JOHN ADAMS, JAMIE BARTRAM, YVES CHARTIER & SIMS, J. (eds.). Geneva: WHO.

WORLD HEALTH ORGANISATION 2011. Guidelines for Drinking-water Quality. 4th ed. Geneva: WHO.

APPENDIX: Assessing the Impact of a School-based Safe Water Intervention on Household Adoption of Point-of-Use Water Treatment Practices in Southern India

Journal: *American Journal of Tropical Medicine and Hygiene*

Authorship order: *Matthew C. Freeman, Thomas Clasen*

Stage of publication: *Published, 2011*

Subject to peer review: *Yes*

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper:

I co-wrote the research proposal and study design, led data cleaning, and executed all analyses. I wrote all drafts of the paper.

Permission to include this publication has been granted by AJTMH. The citation is found at the top of the following page.

Candidate's signature

Supervisor or senior author's signature to confirm role as stated above

Am. J. Trop. Med. Hyg., 84(3), 2011, pp. 370–378
doi:10.4269/ajtmh.2011.10-0361

Assessing the Impact of a School-based Safe Water Intervention on Household Adoption of Point-of-Use Water Treatment Practices in Southern India

Matthew C. Freeman* and Thomas Clasen

Department of Disease Control, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, London, United Kingdom; Center for Global Safe Water, Rollins School of Public Health, Emory University, Atlanta, Georgia

Abstract. We assessed a pilot project by UNICEF and Hindustan Unilever Limited to improve the quality of drinking water for children in schools through adoption of improved drinking water practices among households in southern India. The intervention consisted of providing classrooms of 200 schools a commercial water purifier, and providing basic hygiene and water treatment information to students, parents, and teachers. We found no evidence that the intervention was effective in improving awareness or uptake of effective water treatment practices at home. A similar proportion of household members in the intervention and control groups boiled their water ($P = 0.60$), used a ceramic filtration system ($P = 0.33$), and used a cloth filter ($P = 0.89$). One year after the launch of the campaign, household ownership of the commercial purifier promoted at schools was higher in the intervention group (26%) than the control group (19%), but this difference was not statistically significant ($P = 0.53$).

INTRODUCTION

The World Health Organization (WHO) estimates that improving water, sanitation, and hygiene could prevent at least 9.1% of the global burden of disease and 6.3% of all deaths.[1] Diarrhea represents a significant share of this burden, causing an estimated 4 billion cases and 1.9 million deaths each year of children < 5 years of age, or 19% of all such deaths in developing countries.[2] With over 386,000 deaths attributable to diarrheal diseases per year, India ranks first among countries contributing to this worldwide disease burden.

Although 84% of Indians have access to improved water supply, only 22% have household taps, so that most of the population must collect, transport, and store water in the home.[3] Even water that is safe at the point of distribution is subject to frequent and substantial contamination during collection, transport, and storage.[4] Point-of-use (POU) water treatment, combined with safe storage, is one option for improving the quality of drinking water and reducing the burden of diarrheal disease burden.[5] The WHO and United Nations Children's Fund (UNICEF) recommend POU water treatment as part of an overall strategy for the prevention of diarrheal disease among young children.[6,7]

Promotion of POU products in schools has shown success in reducing diarrheal disease[8] and absenteeism[9,10] among school children in rural Western Kenya. In countries with free primary education, schools may be a way to reach poorer and more marginalized populations with health messages. Children can be effective promoters of health messages, specifically water, sanitation, and hygiene messages,[11] but like all promotional campaigns, success may depend on effective messaging and the appeal of the product to be promoted.[12] However, promotion in schools should be tailored to children with specific tasks to promote peer-to-peer learning and diffusion to households.[13–15]

*Address correspondence to Matthew C. Freeman, Emory University, 1518 Clifton Road NE, GCR 708, Atlanta, GA 30322. E-mail: mcfreem@emory.edu

In September 2007, UNICEF and Hindustan Lever Limited (HUL) collaborated in a pilot study among 200 schools in Krishnigiri District of Tamil Nadu, India designed to provide safe drinking water to children in school while increasing awareness and adoption of effective POU water treatment at home. The intervention consisted of 1) placing a Pureit brand water purification system (HUL) in classrooms, and 2) providing basic instruction to students, parents, and teachers on waterborne diseases and generic information on effective POU water treatment (boiling, chlorination, filtration, solar disinfection, and safe storage). By providing the device to schools, it was hoped that parents would be exposed to the intervention without having to commit to purchasing the device, drawing on key aspects of diffusion of innovations theory, particularly by increasing the visibility of the innovation and allowing it to be experimented with before adoption.[12] We were engaged to assess the pilot.

METHODS

Setting. The pilot was undertaken among 200 primary and middle schools and *anganwadis* (nurseries) in the Krishnigiri and Bargur Administrative Blocks of Krishnigiri District, Tamil Nadu, India. UNICEF selected the catchment area, in part because of concerns about safe drinking water and other environmental risks of diarrheal diseases.[16] In addition to the pilot program described below, the study setting was exposed to commercial activities, including radio and billboard advertising and a microfinance campaign described below, undertaken in India to promote awareness and adoption of the filter used in the intervention.

Pilot program. Over a period of 12 days between December 2007 and January 2008, HUL technicians visited each of the intervention schools to install the purifiers in or just outside the classrooms, with a distribution of 1 device per 50 students. The purifier, which has been described elsewhere,[17] is a gravity-based water treatment system designed for use in settings without reliable water pressure or electric power. The purifier includes a "battery" of consumables (pre-filter, carbon block, chlorine, and granular activated chlorine) designed to

be replaced after treating 1,500 L. The device was supplied with one replacement set of consumables, and classrooms were responsible to organize parents to purchase additional sets. Teachers at each intervention school and Panchayat (town) Presidents from surrounding communities attended a one-day training conducted by UNICEF on water treatment and handling practices. Head teachers at each school were asked to promote safe water messages among teachers and students, organize a rally to promote awareness of the program, and supervise use of the filters at the school. As part of the training, each teacher was provided generic safe water materials to introduce the concept of safe water treatment and handling practices. Topics covered in the training and safe water booklet include causes of fecal contamination of water, diseases spread because of contaminated water, and safe water handling methods. Methods of water disinfection discussed included boiling, chlorination, and solar disinfection as well as advantages and disadvantages for each method.

Integrated Village Development Project (IDVP) campaign. Independent from the pilot, HUL undertook a separate program to support the distribution of purifiers in the study community by IVDP, a microfinance institution (MFI). Under this program, IDVP extends credit to women's self-help groups that can be used, among other things, to acquire purifiers at subsidized prices. The IDVP campaign was extended only to women who were members of the IVDP self-help groups. These trainings were provided to members at self-help group meetings by HUL staff and included education on the benefits of safe water, discussion of Pureit, and a product demonstration. Individual members were free to use their loans to purchase the product. Through September 2009, IVDP had sold 46,000 units throughout the study area, though promotion was not homogeneous in all villages. HUL also began promotion of branded purifiers through radio advertising and billboards.

Assessment design and participant selection. Seventy-two middle and primary schools, stratified evenly between Krishnigiri and Bargur Administrative Blocks, were included in a trial to assess the pilot program. Primary schools from each block were randomly selected to be intervention schools. To control for potential confounding associated with socioeconomic status (SES), climate, and unknown confounders, control schools within the same administrative location were randomly selected as controls. There were 56 primary schools and 16 middle schools included in the baseline sample. Although a baseline survey was attempted by a professional data collection agency, there were irreparable problems with linking cluster-level identifiers at baseline; as such, we are relying here on randomization to render the study arms equivalent in all material respects.[18] Surveys were conducted during a follow-up conducted in February 2009, 12 months after the intervention. To avoid misclassification, 11 (15%) of the schools initially enrolled in the study were not included in the followed up end-line survey because they either were intervention schools that did not receive the intervention or control schools that did receive the intervention (Figure 1).

Sample size. The sample size was calculated assuming a 15% acquisition of filters in the unexposed communities (from a negligible amount at baseline) and expected a difference of 10%. We assumed an intra-cluster correlation

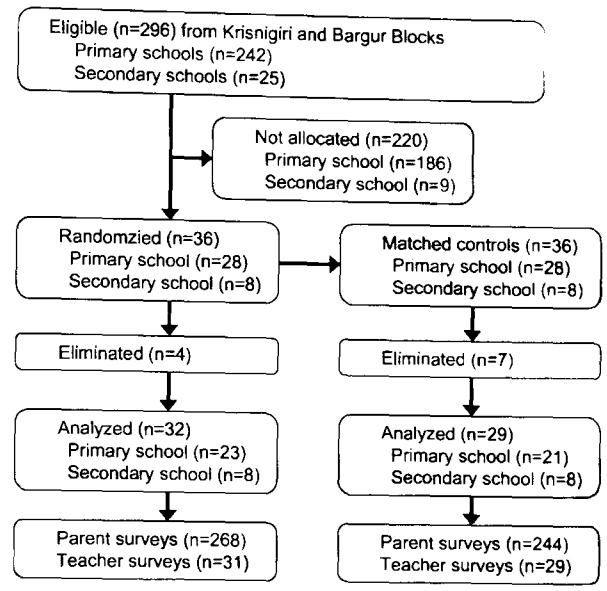


FIGURE 1. School selection.

of 0.05. At each school, pupils were randomly selected from class rosters. Parents of selected pupils were visited at their homes to be interviewed, with preference given to the female head of household. A total of 517 parents were interviewed.

Data collection. Interviews consisted of completing prescribed surveys in which questions were read to the interviewees in Tamil by the data collector. Question topics included knowledge, attitudes, and practices relating to water supply, water treatment, sanitation, and hygiene at school and home. Surveys were originally developed in English, piloted and reverse translated for quality control purposes. Survey data was collected on paper surveys, entered into an electronic database using Microsoft Excel 2007 (Redmond, WA), and analyzed using SAS version 9.2 (SAS Institute, Cary, NC) and STATA version 10 (College Station, TX).

Data analysis. SES was calculated using principal component analysis (PCA) based on indicators taken from the 1999 India Demographic and Health Survey.[19–21] Water and sanitation variables were excluded from the asset index so that they could be modeled individually. Using the factor score generated from PCA, the population was put into wealth terciles. The first principal analysis explained 16.8% of the variance. Education levels were categorized using at least some secondary school and some/completed primary school, using no education as the referent. Statistical significance for univariate and bivariate data was calculated using a chi-square (χ^2) test with one degree of freedom unless otherwise noted. The Cochran-Armitage test for trend and Fisher's exact test were used as appropriate. Significance was assessed at the $\alpha = 0.05$ level and incorporated variance estimations accounting for the clustered study design. For multivariable analysis, outcomes of interest were assessed using mixed effects models generated using the xtlogit procedure in STATA; standard errors are adjusted to account for clustering at the school level.[22] The design variables included in the model were intervention status and school type

(middle versus primary schools). Covariates of interest and confounding variables—SES, membership in a self-help group, education status of female head of household, male head of household education status, having children < 5 years of age in the household, and toilet in compound—were determined *a priori* to data analysis and modeled with intervention status. Potential interaction and effect modification were assessed for all covariates. Because of issues of compatibility between tools and data collection protocols, baseline data were used only for descriptive purposes and were not included in the multivariable models.

Ethics. Prospective study participants were provided details about the study, advised that their participation was completely voluntary and anonymous, and asked to consent to the study before undertaking the surveys. Although the study was an evaluation of a government-authorized program and therefore exempt from Indian ethics approval, the investigators applied for and obtained approval for the study by the ethics committee of the London School of Hygiene and Tropical Medicine and institutional ethics committee of HUL.

RESULTS

Demographics, water, and sanitation facilities. Table 1 provides information on the participating schools, households, and students at follow-up. None of the differences between intervention and control groups was significant at the $\alpha = 0.05$ level. Households from the control and intervention group were statistically similar on key demographic variables such as SES, education level, and household size.

Purifier use and battery replacement in schools. Intervention schools were provided a mean of 3.6 purifiers (range 1–8). On the basis of observation at the school, 84 (88%) of the filters provided were still working at the time of follow-up and 74 (78%) were filled with water at the time of the site visit (Table 1). Assuming that each student drinks 500 mL to 1 L during the 5 hours/day in school,[6] and the school year is 180 days, then the consumables in each purifier would need to be replaced three to six times per year based on the student population. We found that in the 12 months before our survey, just 71% of schools had replaced their consumables after the initial set supplied with the purifier and no school had replaced the batteries more than once.

Safe water awareness. We assessed the knowledge of safe water by asking respondents to list the factors they associate with safe water (Table 2). Over 95% of respondents said that safe water looked clear. More households in the intervention group listed safe water as being free from germs (89% versus 80%, $P = 0.07$) and that it would not make people sick (61% versus 50%, $P = 0.23$) as compared with the control communities. Alternatively, respondents in control communities were more likely to say that safe water does not have a smell (12% versus 22% $P = 0.14$) or tastes good (6% versus 19%, $P = 0.04$) as compared with intervention households. However, only the difference in taste was significant at the $\alpha = 0.05$ level.

Purifier awareness. Purifier awareness was high among all respondents, with no statistical difference between intervention and control groups (90% versus 88%, $P = 0.71$) (Table 2). The most common source of information for both adopters and non-adopters about the purifier came from the self-help group

TABLE 1
School and household demographics

School variables*	Intervention $N = 32$	Control $N = 29$
Number of schools (primary/middle)	24/8	21/8
Mean number of pupils (SD)	120 (85)	144 (130)
Water source is protected (%)	32 (100)	28 (97)
Water is avail throughout year (%)	28 (87)	20 (83)
Mean liters provided per child per day (SD)	1.0 (0.9)	1.1 (0.7)
Mean number of latrines (SD)	1.9 (1.5)	1.8 (1.5)
Mean number of urinals (SD)	2.4 (2.3)	1.8 (1.8)
Use purifier (%)	31 (97)	0 (0)
Median number of filters (range)	2 (0–8)	–
Median number with water (range)	2 (0–4)	–
Median number broken filters (range)	2 (0–4)	–
Number of filters working (%)	26 (81)	–
Number of schools purchased replacement batteries (%)	23 (71)	–
Mean replacement batteries purchased (SD)	1.6 (1.7)	–
Household variables*	**$N = 258$**	**$N = 244$**
Age of respondent (mean)	32 (7)	32 (6)
Respondent is female head of household (%)	231 (86)	215 (88)
In lowest socio-economic tercile (%)	91 (34)	78 (32)
In highest socio-economic tercile (%)	89 (33)	83 (34)
Male head of household at least some education (%)	196 (73)	170 (70)
Female head of household at least some education (%)	165 (62)	132 (54)
Mean family size (SD)	4.9 (1.4)	5.1 (1.5)
At least one child < 5 years of age (%)	61 (23)	132 (54)
Mean number of children < 5 (%)	0.3 (0.5)	0.3 (0.6)
Main water source is protected (%)	266 (99)	64 (26)
Mean no. liters of water used yesterday (SD)	25 (11)	25 (8)

* Data are presented either as the number (%) of responses or the mean (standard deviation) unless otherwise indicated.
† World Bank and World Health Organization Joint Monitoring Program definitions: www.jmp.org.

TABLE 2
Adoption, awareness, and affinity of point-of-use (POU) water treatment

	Intervention (%) N = 271	Control (%) N = 246	P
Households treat water for drinking			
Boil	122 (45)	115 (47)	
Use cloth filter (at source or home)	60 (22)	61 (25)	0.60
Use other filters (candle, ceramic, Pureit)	59 (22)	49 (20)	0.33
What do you understand by "safe water"	64 (24)	39 (16)	0.89
Water looks clear			
Water is free of germs	258 (95)	236 (96)	0.46
Will not make people sick	240 (89)	197 (80)	0.07
There is no dirt in water	164 (61)	123 (50)	0.23
Water does not smell	97 (36)	110 (45)	0.59
Water tastes good	33 (12)	54 (22)	0.14
There are no chemicals	17 (6)	46 (19)	0.04
Pureit	4 (2)	8 (3)	0.76
Heard of Pureit			
From child	244 (90)	216 (88)	0.71
From child's teacher	61 (22)	18 (7)	0.002
From self-help group	141 (52)	23 (9)	< 0.001
Family or friends	195 (72)	177 (72)	0.84
Radio	141 (52)	168 (68)	0.001
Primary message from child or teacher	6 (2)	25 (10)	0.60
Pureit Ownership	59 (25)	7 (3)	< 0.001
Purchased from MFI/SHG (among adopters)	59 (26)	46 (19)	0.53
Among non-adopters	59 (100)	42 (91)	0.03
Likelihood you will purchase Pureit within the next 6 months	N = 182	N = 168	
Very/somewhat likely	83 (46)	111 (66)	0.04
Unlikely/very unlikely	79 (44)	18 (11)	< 0.001
Primary reason you didn't purchase Pureit			
Too expensive	56 (31)	46 (27)	0.63
Not enough money	109 (60)	115 (68)	0.96

(72%). Those in the intervention group were statistically more likely to hear about the purifier from their children's teacher (52% versus 9%, $P < 0.001$) and from their child (22% versus 7%, $P = 0.002$). Those in the control group were significantly more likely to have heard of the purifier from family or friends than those in the intervention group (52% versus 68%, $P = 0.001$). Twenty-five percent of respondents in the intervention group got their primary message about the purifier from their children or teachers at school, as opposed to 3% in the control communities ($P < 0.001$).

Adoption of water treatment methods. Forty-five percent of households reported treating their water to make it safe to drink. The most commonly reported techniques included boiling (24%), using a cloth filter (21%), and using a candle, ceramic, or chlorine-based filter or the purifier (19%) (Table 2). A similar proportion of household members in the intervention and control groups reported boiling (22% versus 25%, $P = 0.60$), using a filtration or purification system (22% versus 20%, $P = 0.33$), and using a cloth filter at the source or at home (24% versus 16%, $P = 0.89$). Ninety-five of the purifiers and filter systems observed in homes were chlorination-based purifiers promoted by the program and self-help groups in the area. The difference in ownership of the purifiers at the end of the year (26% versus 19%, $P = 0.53$) was not statistically significant. Reported reasons for not purchasing the purifier were consistent between the intervention and control groups, with affordability being the major reason given; only 3% of non-adopters reported that they didn't believe they needed a purifier.

Multivariable analysis-awareness. Assessing the effect of the school-based intervention only—while controlling for school type—households in the intervention community had a 1.2 (95% confidence interval [CI] = 0.4–3.1) times greater odds of hearing about the purifier, though the difference was not significant (data not shown). When controlling for confounders (Table 3), awareness among intervention households was not significant. Those in the least poor SES tercile had a 3.6 times greater odds of awareness of a purifier (95% CI = 1.2–10.8) compared with the households in the poorest tercile; the difference between the middle SES tercile and poorest was

TABLE 3
Multivariable model of purifier awareness among household respondents

	OR	95% CI	P
Invention status	1.2	0.4–3.6	
School type (middle vs. primary)	0.4	0.1–1.3	
SES tercile			
Middle vs. poorest	1.7	0.7–4.2	
Least poor vs. poorest	3.6	1.2–10.8	**
Toilet	8.8	0.9–89.4	*
Female head education			
Some/completed primary vs. none	1.9	0.8–5.3	
At least some secondary vs. none	2.5	0.8–7.9	
Male head education			
Some/completed primary vs. none	1.3	0.5–3.3	
At least some secondary vs. none	0.7	0.3–2.0	
Household size	1.1	0.8–1.5	
Child under 5 years in household	2.6	0.9–7.8	*
Female member of self-help group vs. non-member	9.7	4.3–22.1	***

*Significant at $P < 0.1$. **Significant at $P < 0.05$. ***Significant at $P < 0.001$
OR = odds ratio; CI = confidence interval; SES = socio-economic status.

not significant. Respondents who were members of a self-help group had a 9.7 (95% CI = 4.3–22.1) times greater odds of hearing about the purifier; respondents with children < 5 years of age (odds ratio [OR] = 2.6, 95% CI = 0.9–7.8) and households with toilets in their compound (OR = 8.8, 95% CI = 0.9–89.4) had increased awareness, though only to the $\alpha = 0.1$ level.

Determinants of purifier adoption. *Bivariate Associations.* Key covariates assumed *a priori* to data analysis to be associated with purifier adoption are found in Table 4. Unadjusted bivariate associations showed no relationship between intervention and purifier adoption. Socio-economic status, presence of a toilet in the compound, high maternal education, and having some or many friends who own a purifier were all significant predictors of purifier adoption. Adopters were statistically more likely than non-adopters to have heard of a purifier from their self-help group (97% versus 66%, $P < 0.001$) and television (70% versus 44%, $P = 0.001$). Among households in the intervention group, 88% of adopters had seen a purifier at their child's school, as opposed to 76% of non-adopters ($P = 0.05$). Similarly, 7% of adopters had children that brought water home from school, as opposed to 0% of non-adopters ($P < 0.001$). The difference between adopters and non-adopters who had spoken to a teacher or tasted water at the child's school was non-significant.

Multivariate analysis-adoption. Households whose children attended the intervention schools were not more likely to purchase a purifier (Table 5) as determined either by the model adjusting for design variables (OR = 1.3, 95% CI = 0.6–2.6) or with the parsimonious fully adjusted model (OR = 1.2, 95% CI = 0.5–2.7). Those in the middle SES tercile were twice as likely as those in the poorest to own a purifier (OR = 2.3, 95% CI = 1.1–5.2), as were those in the least poor (OR = 2.2, 95% CI = 1.0–4.7). Owning a toilet was also a positive predictor of purifier adoption (OR = 4.4, 95% CI = 1.6–12.2). Similar associations were found in models of awareness: households with female heads belonging to a self-help group were more likely (OR = 34.7, 95% CI = 9.3–130.5) to own a purifier as compared with non-members. The intra-cluster variance (ρ) was 0.26, representing a high degree of the variation explained by the school clusters.

There was no association with the intervention and increased reported use of cloth filtration at the home or water source (model 2: OR = 0.6, CI = 0.2–2.4) or boiling (model 3: OR = 0.4, CI = 0.1–1.2). Increased wealth (OR = 2.6, CI = 1.1–6.0) and toilet use (OR = 3.7, CI = 1.2–11.5) were associated with use of cloth filtration. At least some secondary education among male heads of household was associated with reduced use of cloth filters (OR = 0.4, CI = 0.2–0.9). Having a toilet was also associated with increased boiling (OR = 3.0, CI = 1.1–8.3).

DISCUSSION

There has been increased attention in recent years on promotion of water, sanitation, and hygiene (WASH) in schools.[23] However, most of the work to date has involved implementing organizations assembling lessons learned and best practices.[24,25] To our knowledge, this is the first study using

TABLE 4

Bivariate associations based on adoption of Pureit

	Pureit adopt (%)	Non-adopt (%)	*P*
Demographic and design variables	*N* = 105	*N* = 407	
Intervention	59 (56)	209 (51)	0.54
Self-help group membership	102 (97)	241 (59)	< 0.001
SES tercile			
Middle	39 (37)	132 (32)	0.004
Least poor	46 (44)	126 (31)	0.004
Toilet in compound	28 (27)	40 (10)	< 0.001
Maternal education			
Some/completed primary	27 (26)	124 (30)	0.43
At least some secondary	46 (44)	100 (25)	< 0.001
Paternal education			
Some/completed primary	34 (32)	150 (37)	0.53
At least some secondary	49 (47)	133 (33)	0.007
Friends own			
Few	32 (30)	187 (46)	< 0.001
Some/most	65 (62)	128 (31)	< 0.001
Message drivers of adoption			
Children	19 (18)	55 (14)	0.83
Teachers	31 (30)	111 (27)	0.60
Self-help group	101 (97)	270 (66)	< 0.001
Family/friends	75 (71)	225 (55)	0.02
TV	73 (70)	180 (44)	0.001
Radio	1 (1)	32 (8)	0.08
Sales stalls and kiosks	13 (13)	28 (7)	0.01
School-based drivers of adoption among intervention communities (intervention schools only)	*N* = 59	*N* = 209	
Seen Pureit at school	50 (88)	159 (76)	0.05
Spoken to teacher at school	11 (19)	28 (13)	0.31
Tasted water from Pureit at school	10 (17)	26 (12)	0.37
Child brought water home	4 (7)	0 (0)	< 0.001

SES = socio-economic status.

TABLE 5
Multivariable models of safe water practices (chlorine purifier, cloth filtration, and boiling) among households

Variable	Model 1 – purifier			Model 2 – purifier			Model 2 – cloth filter			Model 2 – boiling		
	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
Invention status	1.3	0.6–2.6		1.2	0.5–2.7		0.6	0.2–2.4		0.4	0.1–1.2	
School type (middle vs. primary)	0.9	0.4–2.1		1.2	0.5–3.1		1.1	0.2–4.5		1.6	0.5–5.4	
SES tercile												
Middle vs. poorest				2.3	1.1–5.2	**	1.3	0.6–3.0		1.5	0.7–3.2	
Least poor vs. poorest				2.2	1.0–4.7	**	2.6	1.1–6.0	**	1.7	0.8–3.6	
Toilet				4.4	1.6–12.2	***	3.7	1.2–11.5	**	3.0	1.1–8.3	**
Female head education												
Some/completed primary vs. none				0.8	0.4–1.6		1.2	0.5–2.9		1.6	0.8–3.3	
At least some secondary vs. none				1.7	0.8–3.7		1.4	0.6–3.3		0.9	0.4–1.9	
Male head education												
Some/completed primary vs. none				1.0	0.5–2.2		0.5	0.2–1.2		1.2	0.6–2.5	
At least some secondary vs. none				1.2	0.5–2.6		0.4	0.2–0.9	**	1.1	0.5–2.3	
Household size				0.8	0.7–1.0	*	1.0	0.8–1.3		1.0	0.8–1.2	*
Child < 5 years of age in household				1.2	0.6–2.4		1.2	0.6–2.5		1.2	0.6–2.3	
Female member of self-help group				34.8	9.3–130.5	***	0.6	0.3–1.2		0.7	0.4–1.3	
Friends own (most/some vs. few/none)				2.8	1.4–5.6	***						

* Significant at $P < 0.1$. ** Significant at $P < 0.05$. *** Significant at $P < 0.001$.
OR = odds ratio; CI = confidence interval; SES = socio-economic status.

an experimental design to assess the impact of school-based water quality interventions to increase the awareness and uptake of effective POU water treatment in the home.

Although our study was not designed to assess the effectiveness of the pilot in providing safe drinking water in schools, our results provide mixed evidence on this issue. A high proportion of the purifiers was functioning and observed to be in use at the time of the site visit. However, it is not clear that the output of the purifier—9 L in 2–3 hours—would be sufficient to meet the needs of 50 students in school for 5 hours. Moreover, as with many school-based WASH programs, sustainability and meeting the recurrent costs of purchasing consumables is a challenge.[26] None of the broken purifiers were replaced and the rate of repurchase of consumables was well below what would be necessary to provide safe water to children during the time of the program implementation.

This study provides no evidence that the intervention was successful in increasing awareness or adoption of boiling, improved storage, or other potentially effective water management practices in homes, including the purifier that was placed in classrooms within the context of the non-experimental promotion through microfinance organizations and using commercial media. Households in the intervention group reported hearing messages about effective water treatment in the home from children and teachers, and the source of messages about the purifier was associated, sometimes strongly, with adoption. However, messages from pupils or teachers in this study were not associated with adoption. The fact that the program did not increase awareness of any of these POU water treatment methods suggests that either the communication strategy was not effective or that other mechanisms were far more influential. High levels of awareness in the control group underscore this finding. As prior research has shown, and teachers know well, the mere delivery of hygiene or any other instruction in a school-based setting is no guarantee of changes in knowledge, much less behavior.[13,14]

There is evidence that the purifier that was used in the pilot could not be adopted by this target population without economic support or without a more targeted marketing approach. Membership in a self-help group was critical to increasing awareness and uptake of the purifier. Self-help groups not only provide credit to members but also to other critical aspects for diffusion through exposure to product demonstrations, early adopters, or changing social norms through exposure with peer influence.[12] It is not clear in this case whether the key mechanism of action for self-help group membership was through promotion, reducing financial barriers to adoption, or creating an enabling social norm, or all of the above. The fact that nearly all respondents who purchased the purifier did so through the self-help group underscores that likelihood that the upfront cost of the product is an important barrier; and the evidence suggests that this barrier is not overcome solely through a school-based intervention aimed at increasing awareness. It is also possible that the success of the self-help group model diluted the potential impact of the pilot program by enhancing the awareness and availability of the specific filter products promoted. These approaches could be seen as complementary, because the self-help groups provided financing and access to the product, whereas the school program provided education and the opportunity to see and test the product.

SES plays a substantial role in which households are aware of the purifier, which households purchased the product and which used cloth filtration. Social marketing typically fails to reach the poorest households and the hypothesis is that promotion in schools will level the disparity typically found in socially marketed durable goods; though promotion of POU products by self-help groups may reach populations typically missed by social marketing.[27] Although those in the lowest tercile in this study were able to access safe water products, the study design did not allow for us to determine if promotion through self-help groups reduced disparity of access over traditional commercial mechanisms. That the interaction between intervention status and SES was not significant in the multivariable model indicates that promotion of the purifier in the school did not reduce the disparity of adoption.

Reaching the poorest and most vulnerable households is critical for a successful safe water intervention, because those most impacted by diarrheal disease mortality are the poorest households with lack of access to health support. We did not find that the intervention had any effect in reducing disparity with respect to awareness or adoption of safe water treatment. Owning a toilet was strongly associated with purifier adoption (and awareness in the case of toilets). Toilet ownership may be an additional proxy for wealth status not captured in the SES factor score. Though, it may also serve as a proxy for hygiene awareness or health seeking behavior.

Those with children < 5 years of age were more likely to have heard about, but not to adopt the commercial filter. On the basis of the association between SES and adoption discussed previously, to reach those at greatest risk of diarrheal diseases, there is a need to either finance the product to reduce front-end cost or find ways to cross-subsidize the product. Cost was the most significant factor identified by non-adopters as a reason they did not purchase the product. Without a means to finance the product—such as through a micro-loan—acquisition is unlikely. In this study, the role of microfinance institutions and self-help groups in providing product access was evident. However, from these data, we are unable to isolate the role of self-help group membership in adoption, whether it was provision of a supply, knowledge about the importance of safe water, financing, or an enabling social norm for treatment of water. Additional research is needed to better understand the drivers of adoption to facilitate promotion of the purifier through self-help groups.

Knowledge of a risk associated with unsafe water is thought to be critical though not sufficient for driving adoption of safe water practices.[28] We did not attempt to identify drivers of adoption, only understand if we increased knowledge in the community. We found limited evidence of correlations that biological and health-based drivers of water treatment (germs cause illness) were more prevalent in intervention communities, and sensory-based beliefs (smell, taste) were more prevalent in control areas. Typically, though acceptability (taste, smell) is often critical in adoption of POU water treatment products,[28] health is often not identified as a key driver of behavior change relating to safe water practices.[29]

We expected that message channels from reliable sources and social norms would play a significant role in behavior change.[12] Although intervention households were more likely to have heard about the product from children and teachers, this did not lead to greater uptake across the program area. Adopters were more likely to have seen the filter at school and have children bring water home; however, the lack of difference between the intervention arms in overall adoption raises questions about influence and causality of these influences. Awareness of the filter product increased dramatically throughout the study area, but it is clear that awareness alone was insufficient to drive acquisition.

The relationship between having friends that own a purifier and adoption underscores the influence of social norms on behavior change. However, having friends that own a purifier may be a proxy for wealth, because those that can afford a purifier also have friends that can afford it, thus helping explain some of the disparity relating to SES. Prestige and status may be a critical driver of filter acquisition, like with other WASH interventions such as hygiene[30] and sanitation.[31] There is need for additional research to understand the role that individual drivers and messages play in POU behavior change and product adoption.

This study had several limitations. First, because the baseline data were unreliable, we were unable to calculate double differences. Because the purifier was largely unavailable before the intervention, we believe that the random selection and matching process mitigated potential imbalance between intervention and control communities. Second, in accordance with the study protocol, we excluded 11 schools from the data analysis that were intended to be included in the study (and therefore part of the allocation of the intervention) but were not actually included in the intervention or the data collection. While this minimizes the risk of misclassification, it prevents a strict intention-to-treat analysis of the results. However, insofar as we found the intervention to be ineffective even among the schools that actually received the intervention, the exclusion of these schools would not impact the results because their inclusion would likely move the point estimate to the null. Third, although these schools were excluded only because UNICEF did not actually reach them when conducting the project, we cannot rule out the possibility that this exclusion was not random, therefore impacting the equivalency of the intervention and control groups in all material respects. Fourth, the parallel promotion activities and the microfinance campaign through self-help groups may have diluted any potential effect of the school-based pilot in terms of both awareness and adoption. Isolation of this pilot from these other commercial activities may have increased the impact of the intervention but would have represented an artificial setting; both UNICEF and HUL sought to examine the additional and targeted contribution the pilot would have in a real world context. The low level of adoption among non-self-help group members underscores the need to pair any promotional campaign for higher-end filters with a mechanism for financing acquisition. A POU water treatment solution with a lower front-end cost may not face the same barriers to adoption and could result in higher uptake by a school-based campaign. Finally, we cannot rule out the possibility that students and parents of control schools were exposed to the purifier through intervention schools, thus resulting in an underestimate of the effect of the intervention.

CONCLUSION

Schools and school children can play an effective role in increasing awareness and adoption of healthful practices and products at home. However, our results, like those in prior studies, show that delivering a WASH intervention at the school level does not guarantee its effectiveness. Interventions at schools require deliberate messaging and activities for children and technologies developed for home use may be inappropriate for use at schools.[32] Although other studies have suggested that schools and children can play a role in securing uptake of healthful interventions at home, our results suggest that at least for household-based water treatment devices with a comparatively high upfront cost, economic status or the availability of credit may be more fundamental to their uptake.

Although the impact of the pilot on uptake may have been diluted because of other promotional activities within the

study population, such as promotion by IVDP and commercial advertising, the evidence suggests that in this context and with a relatively high-cost filter the communication/behavior change strategy (software) was insufficient to increase uptake of effective POU methods at home and that the commercial purifier (hardware) required economic support for adoption that was not included in the intervention. Our results suggest that the school-based intervention in Krishnigiri did not add to the effectiveness of the secular commercial activities undertaken to promote the purifier in India, and that access to a microfinance organization was a more effective vehicle for overcoming the barriers to adoption of effective POU at home, at least in the case of options such as the purifier with a comparatively high upfront cost.

Received June 24, 2010. Accepted for publication December 13, 2010.

Acknowledgments: This study would not have been possible without the work of a number of people. First, we thank Mr. Ganeshmoorthi and Mr. Deveraj of UNICEF, the main implementers of the project, for their tireless work and dedication. Our partners at AC Nielson—specifically, Shruti Ramaswamy, Rohini Sundar, and Ajay Macaden—were a pleasure to work with and provided invaluable support in survey design and data collection. The formative work of Mary Pat Clasen, Helen Tipper, and Mari Watanabe were critical for the study design. Of course, the work would not have been possible without the participation of teachers and community members in the program schools. Finally, we would like to thank HUL for providing funding for the assessment and Shailesh Gupta for his support during program evaluation.

Financial support: Matthew Freeman and Thomas Clasen are members of the staff of the London School of Hygiene and Tropical Medicine, which receives funding for research from both UNICEF and HUL. The cost of this assessment was paid by HUL, though the sponsoring agency did not play a role in data collection or analysis.

Authors' addresses: Matthew C. Freeman, Center for Global Safe Water, Rollins School of Public Health, Emory University, Atlanta, GA, E-mail: mcfreem@emory.edu. Thomas Clasen, Department of Disease Control, Environmental Health Group, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, London, United Kingdom, E-mail: Thomas.clasen@lshtm.ac.uk.

REFERENCES

1. Pruss-Ustun A, Bonjour S, Corvalan C, 2008. The impact of the environment on health by country: a meta-synthesis. *Environ Health 7:* 7.
2. Boschi-Pinto C, Velebit L, Shibuya K, 2008. Estimating child mortality due to diarrhoea in developing countries. *Bull World Health Organ 86:* 710–717.
3. UNICEF, World Health Organization (WHO), 2010. *Progress on Drinking Water and Sanitation: 2010 Update*. New York: UNICEF; Geneva: WHO.
4. Wright J, Gundry S, Conroy R, 2004. Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Trop Med Int Health 9:* 106–117.
5. Clasen T, Schmidt WP, Rabie T, Roberts I, Cairncross S, 2007. Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *BMJ 334:* 782.
6. World Health Organisation (WHO), 2009. *Water, Sanitation and Hygiene Standards for Schools in Low-cost Settings*. Geneva: WHO.
7. World Health Organisation (WHO), 2008. *Guidelines for Drinking Water Quality*. Geneva: World Health Organization.
8. Migele J, Ombeki S, Ayalo M, Biggerstaff M, Quick R, 2007. Diarrhea prevention in a Kenyan school through the use of a simple safe water and hygiene intervention. *Am J Trop Med Hyg 76:* 351–353.
9. Blanton E, Ombeki S, Oluoch G, Mwaki A, Wannemuehler K, Quick R, 2010. Evaluation of the role of school children in the promotion of point-of-use water treatment and handwashing in schools and households–Nyanza Province, Western Kenya, 2007. *Am J Trop Med Hyg 82:* 664–671.
10. O'Reilly CE, Freeman MC, Ravani M, Migele J, Mwaki A, Ayalo M, Ombeki S, Hoekstra RM, Quick R, 2008. The impact of a school-based safe water and hygiene programme on knowledge and practices of students and their parents: Nyanza Province, western Kenya, 2006. *Epidemiol Infect 136:* 80–91.
11. Snel M, Ganguly S, Shordt K, 2002. *School Sanitation and Hygiene Education–India: Handbook for Teachers*. Technical Paper Series no. 39. Delft. The Netherlands: International Water and Sanitation Centre.
12. Rogers EM, 2003. *Diffusion of Innovation*. New York: The Free Press.
13. Onyango-Ouma W, Aagaard-Hansen J, Jensen BB, 2005. The potential of schoolchildren as health change agents in rural western Kenya. *Soc Sci Med 61:* 1711–1722.
14. Bowen A, Ma H, Ou J, Billhimer W, Long T, Mintz E, Hoekstra M, Luby SP, 2007. A cluster-randomized controlled trial evaluating the effect of a handwashing-promotion program in Chinese primary schools. *Am J Trop Med Hyg 76:* 1166–1173.
15. Hunter PR, 2009. Household water treatment in developing countries: comparing different intervention types using meta-regression. *Environ Sci Technol 43:* 8991–8997.
16. Banda K, Sarkar R, Gopal S, Govindarajan J, Harijan BB, Jeyakumar MB, Mitta P, Sadanala ME, Selwyn T, Suresh CR, Thomas VA, Devadason P, Kumar R, Selvapandian D, Kang G, Balraj V, 2007. Water handling, sanitation and defecation practices in rural southern India: a knowledge, attitudes and practices study. *Trans R Soc Trop Med Hyg 101:* 1124–1130.
17. Clasen T, Nadakatti S, Menon S, 2006. Microbiological performance of a water treatment unit designed for household use in developing countries. *Trop Med Int Health 11:* 1399–1405.
18. Rothman K, Greenland S, Lash T, 2008. *Modern Epidemiology*. Philadephia, PA: Lippincott, Williams & Wilkins.
19. Gwatkin DR, Rutstein S, Johnson K, Suliman E, Wagstaff A, Amouzou A, 2007. *India: Socio-Economic Differences in Health, Nutrition, and Population*. New York: World Bank.
20. Vyas S, Kumaranayake L, 2006. Constructing socio-economic status indices: how to use principal components analysis. *Health Policy Plan 21:* 459–468.
21. Gwatkin DR, Rutstein S, Johnson K, Suliman E, Wagstaff A, Amouzou A, 2007. Socio-economic differences in health, nutrition, and population: India. *Socio-Economic Differences in Health, Nutrition, and Population*. Washington, DC: World Bank.
22. Rabe-Hesketh S, Skrondal A, 2008. *Multilevel and Longitudinal Modeling Using Stata*. College Station, TX: Stata Press.
23. UNICEF, 2010. *Raising Clean Hands: Advancing Learning, Health, and Participation through WASH in Schools*. New York: UNICEF.
24. Snel M, 2004. *The Worth of School Sanitation and Hygiene Education*. Delft, Netherlands: International Water and Sanitation Centre (IRC).
25. UNICEF, International Water and Sanitation Centre (IRC), 2005. Water, sanitation and hygiene education for schools roundtable meeting. *Roundtable Proceedings and Framework for Action*. Oxford, UK.
26. Saboori S, Freeman M, Odhiambo M, Kimo S, Mwaki A, Okech B, Rheingans R, 2009. Sustaining school-based point-of-use water treatment in Western Kenya. *137th American Public Health Association Annual Meeting and Exposition*. Philidelphia, PA.
27. Freeman M, Quick R, Abbott D, Ogutu P, Rheingans R, 2009. Removing barriers to point-of-use water treatment products through social marketing and entrepreneurship: a case study in Western Kenya. *J Water Health 7:* 527–534.

28. Figueroa M, Kincaid D, 2007. Social, cultural and behavioral correlates of household water treatment and storage. Geneva: World Health Organization.
29. Pinfold JV, 1999. Analysis of different communication channels for promoting hygiene behaviour. *Health Educ Res 14:* 629–635.
30. Curtis V, Kanki B, Cousens S, Diallo I, Kpozehouen A, Sangare M, Nikiema M, 2001. Evidence of behaviour change following a hygiene promotion programme in Burkina Faso. *Bull World Health Organ 79:* 518–527.
31. Jenkins MW, Scott B, 2007. Behavioral indicators of household decision-making and demand for sanitation and potential gains from social marketing in Ghana. *Soc Sci Med 64:* 2427–2442.
32. Sidibe MA, 2007. Can hygiene be cool and fun? Understanding school children's motivations to use their school toilets and wash their hands with soap in Dakar, Senegal. London, UK: London School of Hygiene and Tropical Medicine.