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Predictors and Effects of Community Sanitation

for Control of Neglected Tropical Diseases in Amhara Region, Ethiopia

By

William Edward Oswald

Doctor of Philosophy

Epidemiology

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An abstract of

a dissertation submitted to the Faculty of the

James T. Laney School of Graduate Studies of Emory University

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in Epidemiology

2015

Abstract

Predictors and Effects of Community Sanitation

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By William Edward Oswald

Sanitation, or safe disposal of human excreta, is fundamental to a hygienic living environment and to public health. Neglected Tropical Diseases, like trachoma and soil-transmitted helminth (STH) infections, occur under unhygienic conditions and predominantly affect children. Sub-Saharan Africa suffers from low levels of sanitation access, and heterogeneity in sanitation access also exists within countries in this area. Few studies have examined the relationship between these diseases and sanitation access as a community measure or reasons for geographic heterogeneity in community sanitation. This dissertation examined these questions using data combined from five surveys conducted across Amhara Region, Ethiopia between 2011-2014 by the Amhara Regional Health Bureau and The Carter Center's Trachoma Control Program.

The first two studies aimed to estimate the effect of community sanitation on prevalence among children of active trachoma and infection with three STH (*Ascaris lumbricoides*, *Trichuris trichiura*, hookworm). Multilevel analyses were conducted using generalized linear mixed models, accounting for complex survey design. The first study found that increased community sanitation was associated with decreased prevalence odds of active trachoma among children, aged 1 to 9 years, following 5 years of trachoma-control activities. The second study found no evidence of a protective association of increased community sanitation with prevalence of STH infection among children, aged 6 to 15 years. Hookworm prevalence was not associated with community sanitation. *T. trichiura* and *A. lumbricoides* prevalence was higher in communities with higher sanitation. Association of community sanitation with *A. lumbricoides* prevalence depended on household sanitation.

The third study aimed to develop and validate a model to predict low community sanitation. Logistic regression was used with remote-sensing and other data on environmental and social conditions. The selected model predicted low community sanitation with reasonable discrimination and was used to generate a risk map of poor community sanitation for Amhara Region.

These studies demonstrate the need for increased community sanitation to reduce trachoma prevalence and further research to clarify the role of community sanitation in preventing STH infections. Predictive modeling using environmental and social conditions can assist health and sanitation programs to identify areas that need additional or alternate sanitation interventions.

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Acknowledgments

I owe thanks to many for support, suggestions, answers, and advice while completing this dissertation. Specifically, thank you to my committee: Christine Moe, who has been a great supervisor, travel companion, mentor, and friend, throughout my time at Emory; Thomas Clasen, whose insight, advice, and humor have supported me at the most challenging times; Michael Kramer, who has spent uncounted hours working with me and responding to my questions; Dana Flanders, whose questions have challenged me and refined my understanding as an epidemiologist; and Paul Emerson, who invited me in to the fascinating world of Neglected Tropical Disease research.

Thank you to all the faculty and staff of the Rollins School of Public Health, for their instruction, help, and kindness over the years, in particular: Dr. Penny Howards, Dr. Mitch Klein, Dr. David Kleinbaum, and the late Dr. Harland Austin. Thanks also to Jena Black and Julie Gazmararian for providing sympathetic ears and support throughout this process.

Thanks to The Carter Center's Trachoma Control Program for providing their unique data and financial support for me to conduct this research. Thanks also to the ARCS Foundation of Atlanta and the Laney Graduate School for funding this work.

Finally, thanks to my friends and family, whose consistent support has encouraged me through this process.

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List of Abbreviations

AIC - Akaike Information Criteria
AL - Ascaris lumbricoides
AT - Active Trachoma
AUC - Area Under the Curve
CI - Confidence Interval
CLTS - Community-Led Total Sanitation
CO - Corneal Opacity
DAG - Directed, Acyclic Graph
DNA - Deoxyribonucleic acid
DT - Development Team
EE - Environmental Enteropathy
GEE - Generalized Estimating Equations
GET2020 - Global Alliance for the Elimination of Blinding Trachoma by the year 2020
HIV - Human Immunodeficiency Virus
HW - Hookworm
MDA - Mass drug administration
MDG - Millennium Development Goals
MOR - Median Odds Ratio
NAATS - Nucleic acid amplification tests
NGO - Non-governmental Organization
NHSS - (Ethiopian) National Hygiene and Sanitation Strategy
NTDs - Neglected Tropical Diseases
OR - Odds Ratio
PR - Prevalence Ratio
QIC - Quasilikelihood under the Independence model Criterion
RNA - Ribonucleic acid
SAFE - Surgery, Antibiotics, Facial Cleanliness, Environmental Improvements
SES - Socioeconomic Status
SRTM - NASA Shuttle Radar Topographic Missioin
STH - Soil-transmitted Helminth
TF - Trachomatous Inflammation - Follicular
TI - Trachomatous Inflammation - Intense
TS - Trachomatous Scarring
TT - Trachomatous Trichiasis
TT - Trichuris trichiura
UNICEF - United Nations Children’s Fund
UTM - Universal Transverse Mercator
VIP - Ventilated, Improved Pit Latrine
WASH - Water, Sanitation, and Hygiene
WGS - World Geodetic System
WHO - World Health Organization

Chapter 1 - Introduction

Globally, it is estimated that in 2011, 15% of the world's population or just over 1 billion people lacked access to any sanitation facility and defecated in the open (1). Of people without sanitation, 71% live in rural areas, where 90% of all open defecation occurs (1). This crisis remains despite progress made in the past two decades; rates of open defecation have declined from 24% in 1990, and in 2011, 64% of the world population had access to improved sanitation facilities (1). In contrast to other basic services, like water supply, that have outpaced population growth, over the past two decades, the provision of improved sanitation has barely managed to keep up with population growth (2). It is forecast that global efforts will not meet the United Nations' Millennium Development Goal (MDG) 7, Target C, that aimed to reduce by half the proportion of people without sustainable access to basic sanitation (3). As such, the goal of extending sanitation coverage to 75% of the world's population by 2015 will be missed by more than half a billion people (1).

The safe disposal of human excreta, alongside sufficient and safe access to water for personal hygiene and drinking, is fundamental to a hygienic living environment and public health. In Europe and North America, increasing access to sanitation and safe water over the course of the last two centuries coincided with a reduction in infectious diseases. In areas of the world lacking access to adequate water supplies and household sanitation, unhygienic living conditions give rise to 17 diseases recognized as Neglected Tropical Diseases (NTDs), such as trachoma and soil-transmitted helminth (STH) infection. Resulting from infection by a variety of pathogens, NTDs affect more than 1 billion people worldwide and are endemic in 149 countries (4). The NTDs are considered diseases of poverty as they most commonly afflict the 2.7 billion people who live on less than $2 per day, in rural and poor urban areas of low-income countries in sub-Saharan Africa, Asia, and Latin America (5).

One unifying characteristic of these diseases is their low mortality but significant levels of morbidity and long-term disability, which contribute to the impoverishment of those suffering from the diseases and the renewal of the cycle of poverty among these populations (5). Fortunately, another unifying characteristic of the NTDs, particularly trachoma and STH infection, is the availability of economical (or donated) and highly-effective medicines. This availability has heralded the opportunity to eradicate or eliminate many of these conditions. The World Health Organization (WHO) aims to eliminate global blinding trachoma and aims to reach 75% coverage with anthelmintic administration in pre-school and school-age children in all countries by 2020 (6). The current progress towards this aim led to renewed commitment in 2013 by the leadership of the WHO to support member states and other initiatives in their efforts to control these diseases (7).

Unprecedented progress towards these elimination aims has been made, but limited access to water and hygienic excreta disposal facilities remains a barrier to the elimination and eradication of NTDs (6). Despite widespread recognition of the importance of sanitation access and adequate water for hygiene to ensure a clean living environment, the current "roadmap" to control many of these diseases does not explicitly describe the means or methods to ensure sustainable access to sanitation and water, though it is identified as a long-term priority (8, 9).

There is growing recognition of the need to integrate efforts to control the NTDs with the sanitation, hygiene, and water (WASH) sector in order to bring about a sustained impact (10). This recognition is promising, and it is possible that the results of the combined efforts are greater than the sum of their parts. Poverty, its associated poor living conditions, and resultant diseases exist in a self-perpetuating cycle, so efforts to reduce global poverty must ameliorate poor living conditions through sanitation and address associated diseases. Yet, questions still remain about the relationship between sanitation and NTDs that must be answered in order to bring about long-term control and eventual elimination of these diseases. Furthermore, the failure to meet the MDG target for sanitation reflects, among other factors, only limited understanding of how best to implement sanitation interventions.

The overall objective of this dissertation is to estimate the effect of sanitation upon the prevalence of trachoma and STH infections under various programmatic, environmental, community, and household conditions, and to assess how environmental and social conditions may influence community uptake of sanitation.

Aims of Dissertation

Aim 1) Estimate the effect of sanitation usage at the community level on prevalence of active trachoma among children, aged 1-9 years, in Amhara Region, Ethiopia, following 5 years of SAFE implementation.

Aim 2) Estimate the effect of sanitation usage at the community level on prevalence of soil-transmitted helminth infection among children, aged 6-15 years, in Amhara Region, Ethiopia.

Aim 3) Develop and validate a diagnostic tool for estimating the probability of a community having low sanitation coverage based on its environmental and social conditions.

These aims will be addressed through the remainder of this dissertation. Chapters 2 and 3 provide background on the neglected tropical diseases of trachoma and STH infection, respectively. Chapter 4 provides background on sanitation, particularly on-site solutions, reviews our understanding of the role of sanitation on human health, discusses sanitation as a household and community conceptualization, and ends with a review of the relationship of environmental and social conditions with sanitation. Chapters 5-7 are manuscripts describing the methods and results from studies to address aims 1-3. Finally, chapter 8 concludes by summarizing each study's findings, strengths, limitations and the overall implications of this dissertation.

Chapter 2 - Trachoma

Global Burden of Disease

Trachoma remains the leading cause of infectious blinding worldwide, and it is estimated that approximately 1.3 million people are blind because of this disease and a further 1.8 million have low vision (11). It was recently estimated that 40.6 million people suffer from active trachoma, while 8.2 million have trichiasis (12). These levels represent a decline in active trachoma from a WHO estimate of 84 million made in 2003. These declines are attributed to earlier overestimations from India and China, along with socioeconomic development in some countries, and intervention activities in areas with slower development (12). Estimates of trichiasis have actually increased from 7.6 million in 2004, but this change is attributed to newly available data (12)

Approximately half of all active trachoma cases are concentrated in five countries: Ethiopia, India, Nigeria, Sudan, and Guinea, while 50% of the global burden of trichiasis is concentrated in China, Ethiopia, and Sudan (12). Approximately 68 percent of all cases of active trachoma, or 27.8 million, and 47 percent of all cases of trichiasis, 3.8 million, are in Africa (12). The highest prevalences of disease are found in sub-Saharan Africa, particularly in the Sahel belt of West and savannahs of East and Central Africa (13).

Currently, the geographical distribution of trachoma is predominantly in hot, arid areas of the world, but this has not always been the case (14). At the beginning of the 19th century, trachoma became a major public health problem in more temperate Europe, possibly being carried back by soldiers returning from the Napoleonic wars in Egypt (15). Based on evidence that the prevalence of trachoma is not inversely related with access to water, it has been suggested that the disease's current endemicity in hot and arid areas may just be a "proxy for poverty" in the modern world (14). As with other Neglected Tropical Diseases (NTDs), trachoma is predominantly found in resource-poor, rural communities in low-income countries (13, 15). Trachoma afflicts the most deprived people in the world, leading to disability, dependency, and further poverty (14).

Clinical Features

Trachoma is a chronic inflammation of the conjunctiva, the inner lining of the eyelids. It is caused by recurrent infection with Serotypes A, B, Ba, and C of *Chlamydia trachomatis*, an obligate intracellular gram-negative bacterium. In contrast, Serotypes D-K mainly affect epithelial surfaces of the genital tract and cause sexually-transmitted disease (16).

Clinical signs of trachoma are comprised of two distinct but overlapping phases (16) and change with age (13). The first phase, active trachoma, is most commonly found in young children (15, 16), and in some developing countries it is an endemic childhood disease (17). During the active trachoma phase, the signs and symptoms of inflammation resulting from episodes of infection with *C. trachomatis* are apparent. The second phase is the pathological tissue responses to inflammation, consisting of scarring, trichiasis, and corneal opacity and is most observed in late childhood and adults (15, 16).

Active trachoma is diagnosed by examining the conjunctiva of the everted upper eyelid, and the key sign is the appearance of lymphoid follicles (16). Follicles are round lumps or spots, gray or creamy in color, up to 3 mm in diameter (18). Follicles smaller than 0.5 mm in diameter or those not in the center of the conjunctiva may be normal and are not considered active trachoma (18). More severe cases are characterized by thickening and swelling of the conjunctiva leading to a “velvety” appearance (16). In addition, papillae (papillary hypertrophy), or vascular structures that appear as red swellings, may appear, and the intensity of their appearance reflects inflammation severity (16). Even in the presence of severe inflammation, individuals are frequently asymptomatic or have only mild symptoms, similar to those associated with any chronic conjunctivitis: redness, discomfort, tearing, photophobia, and scant muco-purulent discharge (15).

Episodes of infection and resulting conjunctivitis are self-limiting, but repeated infections and resultant inflammation during childhood lead to scarring of the conjunctiva (16). Initially, scarring on the conjunctiva from trachoma appears as a few linear or star-like scars, but eventually these coalesce into a dense “basket-weave pattern” (16) and thick, distorting bands of fibrosis, such as Arlt’s line that characteristically forms near the lid margin (15, 16). This scarring alters the structure of the eyelids in such a way that the margin of the eyelid is pulled inwards (entropion), causing lashes to painfully rub the surface of the eye, a condition called trichiasis. Trichiasis can rapidly lead to damage of the cornea, which becomes opaque, and eventually to blindness (16). Opacification likely results from the mechanical trauma of lashes rubbing on the eye but also secondary bacterial or fungal infection and a dry ocular surface (15).

Detection of Disease and Infection

In response to the need for a tool to identify populations and individuals with the blinding form of the disease and to rapidly assess changes in the pattern of disease over time, a simple grading system was developed (19). In contrast to earlier methods of scoring clinical signs, the simplified system was suitable for use by non-specialist health personnel, allowing them to make a reliable assessment of trachoma and its severity based on the presence or absence of 5 key signs (19):

- *Trachomatous inflammation – follicular (TF)* – the presence of 5 or more follicles at least 0.5 mm in diameter in the central part of the upper tarsal conjunctiva
- *Trachomatous inflammation – intense (TI)* – pronounced inflammatory thickening of the upper tarsal conjunctiva obscuring more than half the normal deep tarsal vessels
- *Trachomatous scarring (TS)* – the presence of easily visible scars in the tarsal conjunctiva
- *Trachomatous trichiasis (TT)* – at least one eyelash rubbing on the eyeball or evidence of recent removal of in-turned eyelashes
- *Corneal opacity (CO)* – easily visible corneal opacity over the pupil, so dense that at least part of the pupil margin is blurred when viewed through the opacity

First, the eye is examined using binocular loupes (x2.5) and adequate lighting for the presence of inturned eyelashes (TT) and any corneal opacity (CO). The upper eyelid is then turned over (everted), and the tarsal conjunctiva is examined for the presence of trachomatous inflammation characterized by the two types of conjunctival reaction: predominantly follicular inflammation (TF) and intense inflammation (TI) with diffuse thickening. Severe thickening is considered to be more infectious, regardless of the number of follicles present, but these conditions may occur together and should both be recorded (19). Finally, the everted eyelid is examined for the presence of scarring (TS). Each eye is examined and assessed separately, and if there is any doubt, the sign is considered absent (19).

While trachoma is diagnosed clinically, the detection of *C. trachomatis* infection is a challenge, particularly at the scale needed for trachoma control activities within the remote, rural settings most afflicted by the disease. Culture procedures are currently the only method to identify living *C. trachomatis*, and serological tests have limited diagnostic value (16). Culture procedures have very high specificity, limited sensitivity, and are difficult and time consuming (16). More recently, nucleic acid amplification tests (NAATs), based on chlamydial DNA and, with greater sensitivity, rRNA, have been used to detect infection (20). Problematically, the results of these tests generally show poor correlation with clinical grading, varying depending on severity and prevalence (16). For example, in low prevalence communities, particularly following MDA, among individuals with active disease only a minority are found to be infected, and conversely, in endemic communities, infection can be detected among individuals who do not meet WHO criteria for disease (15).

Disease kinetics can partially explain this lack of correlation (16). The incubation period is time from infection to clinical appearance of symptoms. It is followed by a patent phase when symptoms of disease and infection concur. Finally, during the recovery phase, symptoms may persist but the organism has been cleared. Due to the infectiousness of chlamydia and long recovery, individuals may cycle between the patent and recovery phases, clearing the organism quickly but becoming re-infected before clinical symptoms have resolved (16). Other factors that may contribute to the discrepancies between NAAT results and clinical diagnosis include: the short incubation period; the use of the simplified grading system (judging trachomatous inflammation based on the number of follicles may miss mild cases); errors in grading; contamination of samples or false-positive results; nonchlamydial causes of conjunctivitis; and potential asymptomatic carriage of infection (16). Nonchlamydial pathogens have been associated with symptoms similar to trachoma, and recent studies indicate that an inflammatory state not attributable to chlamydial infection may lead to conjunctival scarring (20). Potential asymptomatic carriage holds significant implications for disease control efforts that base targets on clinical grading and not infection status (16). Based on the disagreement between NAATs and grading, others have suggested that mass drug administration be based on diagnosis of infection and highlighted the need for a cheaper and more efficient test (21).

Transmission

Trachoma remains in endemic communities because of continued transmission of *C. trachomatis* from infected to susceptible individuals (13). Transmission occurs through a variety of mechanisms of varying importance that include (15): direct spread from eye to eye during close contact, such as play or sleep; spread of infected ocular or nasal secretions on the fingers; indirect spread by fomites, such as towels or bedding; transmission by eye-seeking flies; and possible spread from nasopharyngeal infection by aerosol.

Trachoma clusters in certain communities, within certain households, particularly those with young children (16). The main reservoir of infection is considered to be the eyes of infected people, particularly preschool-age children, who have the greatest prevalence of active trachoma and longer duration of infections (14). Proximity to children and exposure to repeated infection during child caregiving potentially explains why adult women are more likely than men to exhibit signs of active disease, bear infection, and have greater risk of developing trichiasis (22). A meta-analysis of 24 prevalence surveys worldwide found that the odds of trichiasis were between 1.6 and 2 times higher among women compared to men (OR=1.82, 95%CI 1.61—2.07) (23). Sharing a room with an active case is also a major risk factor that reflects the facile nature of transmission (14). Similarly, crowded living conditions may increase the risk of trachoma, but this relationship is unclear and may be confounded by crowded families being larger, with more pre-school aged children, and greater poverty (14).

Control and Prevention

In 1997, the World Health Organization, in partnership with various nongovernmental organization and national health services, launched the Global Alliance for the Elimination of Blinding Trachoma by the year 2020 (GET 2020), in line with the Vision 2020 initiative that aimed to more generally eliminate avoidable blindness by the year 2020 (24, 25). Because infection and active disease are clustered in households, control efforts should be community-based to “interrupt transmission to other children and adults, by isolating infectious secretions and treatment of infection” (26). The SAFE strategy is a comprehensive approach combining 4 community-based control measures based on epidemiologic and biologic evidence (26, 27). SAFE includes: Surgery for the correction of trichiasis, Antibiotics to reduce the reservoir of infection in the community, Facial cleanliness to reduce transmission, and Environmental improvements, such as control of flies and access to water, to further reduce the potential for transmission.

Surgery

Within SAFE, surgery is targeted at the blinding stage of disease, trichiasis, but is not sight-restoring. As the only effective management for trichiasis, surgical intervention, specifically bilamellar tarsal rotation, will remain necessary for the foreseeable future even as the prevalence of active trachoma decreases (16). In fact, even if active trachoma were eliminated today, people would still be at risk of developing trichiasis and subsequent blindness (26, 27). Trichiasis may still develop in people because of the infections they faced in the past (22).

Surgical programs face the challenge of high recurrence and poor acceptance. Under ideal, meticulous conditions recurrence rates are low, but, after 2 or 3 years, rates in practice vary from 20-60% and are potentially related to the quality of the surgery, presence or signs of infection, types of sutures used, and minor variations in technique (16). Some reoccurrence is also expected through the natural progression of the disease (16). Evidence indicates that women are more likely to have recurrence than men (22), and it has been recommended that women be specifically targeted for trichiasis surgery because of the potential for gender bias (23). Women, particularly elderly women, may not have access to cash to pay for service or power within the family structure to demand cash resources for surgery (26). Recurrence also undermines acceptance of the procedure, by decreasing patient confidence and leading to frustration among surgical teams (26). Major barriers to acceptance of surgery that have been identified include lack of awareness of surgery, fear, perceived direct and indirect costs, and transport difficulties (16). These challenges remain to be addressed for the final elimination of this form of preventable blindness.

Antibiotics

As a community disease, if only isolated cases are treated then reinfection with trachoma is likely, so mass antibiotic treatment is used to reduce the community reservoir of chlamydial infection (16, 26). The feasibility of this approach was enhanced by the advent of the macrolide antibiotic, azithromycin, which is capable of treating active trachoma with one or a few doses, and the donation of this expensive drug by Pfizer (27). The targeting of mass drug administration is based on the prevalence of active trachoma. Where baseline district prevalence of TF in 1-9 year old children is 10% or greater, antibiotic treatment of all residents should be undertaken annually for 3 years, after which prevalence should be reassessed (16, 18). WHO recommends an annual dose of the macrolide antibiotic azithromycin (20 mg/kg up to 1 g), or if azithromycin cannot be taken, topical tetracycline ointment can be used twice daily for 6 weeks (16). The single dose of azithromycin has advantages over tetracycline including greater adherence, a low resistance potential, fewer side effects, and favorable effects on other “extraocular” disorders, but questions remain about the timing of mass treatment and the necessary duration of treatment to prevent re-emergence of the disease (16).

Facial Cleanliness

Chlamydia trachomatis is transmitted between people through contact with ocular and nasal secretions, so the lack of facial cleanliness is potentially the most important modifiable risk factor for trachoma transmission (16). Accordingly, improvements to facial cleanliness aim to reduce the possibility of transmission by removing infectious secretions from faces and hands (28). A clean face may not only reduce the likelihood of direct transmission, but in a field study, children without ocular and nasal discharges had fewer fly-eye contacts, indicating that transmission by flies may also be reduced by facial cleanliness (29).

Much of the evidence of a relationship between facial cleanliness and trachoma is based on cross-sectional studies. A meta-analysis found a significant protective relationship between a clean face, or the lack of ocular or nasal discharge, and active trachoma, but the authors highlighted, as have others, how the direction of causality could not be established from these cross-sectional studies because lack of facial cleanliness is both a risk factor for and consequence of disease (16, 30). Another challenge regarding the evidence of a protective effect from facial cleanliness is the lack of a standardized definition of “clean face” (28). A randomized, controlled trial found that the presence of ocular and dry nasal discharge was a repeatable definition, suitable for monitoring purposes, but because of the association between ocular discharge and the definition’s poor sensitivity for predicting face washing, the authors could not fully recommend the measure (28). While the measurement of a clean face remains a challenge, more frequent face washing was also shown through meta-analysis to be negatively associated with the presence of active trachoma (30). Improved access to water to facilitate behavior change and better hygiene should be included among environmental improvement for trachoma control (16).

Environmental Improvements: Water Supply & Trachoma

Despite only limited epidemiologic and some biologic evidence of the relationship between sanitation and trachoma, environmental improvements such as access to household excreta disposal facilities and water, are included in the SAFE strategy to eliminate blinding trachoma by 2020. Environmental improvements are considered the definitive interventions for active trachoma based on the fact that trachoma has been eliminated from all developed cities in the world (16).

The poor community hygiene and conditions less amenable to personal hygiene, frequently found in areas of extreme poverty, contribute to transmission of chlamydial infection and resultant trachoma (16). Trachoma is more common in hot, dry areas of the world, which might indicate that the scarcity of water and resulting lower levels of personal hygiene contribute to the disease. Despite having been widely studied in many settings, however, plausible mechanisms relating water availability, use, hygiene, and subsequent trachoma transmission levels remain unclear (13-15). In their review, Emerson *et al*. document a number of potential but inconclusive mechanisms, including water permitting increased frequency of laundry, use of water for personal hygiene to reduce transmission on fingers, and face-washing (2000). In their meta-analysis, Stocks *et al*. found that distance to water (when reported as ≤1km distance or <30 min collection time) was not significantly associated with active disease (TF/TI) (OR 0.97, 95%CI 0.83--1.11) or *C. trachomatis* infection (OR 1.08, 95% CI 0.86--1.30) (30). It is unclear from this meta-analysis whether the estimated measures of association were obtained from multivariate models including measures of hygiene. It is likely that the relationship of water availability with trachoma is mediated by the use of water for hygiene.

Emerson *et al.* explained the contradictory results regarding distance to water and risk of trachoma with the observation by Cairncross & Feachem (31) that per capita water consumption, or use, is often constant between households when the round trip to a water source is 30 min or less (2000). Kuper *et al.* similarly asserted that distance to water limits the availability of water for use at the household, and described how there was no association of use with trachoma when the distance was small because of this "water-use plateau" (32). Pruss & Mariotti highlighted the greater opportunity for confounding bias with more indirect environmental risk factors, such as water availability, and the difficulty of disentangling their causal effects (33). Water usage for washing would be a more proximate measure, but it is difficult to measure in a uniform manner in large-scale studies. Regarding water use, despite few studies, Stocks *et al*. found an association between using more water for washing and lower odds of trachoma, though the significance of these results was mixed (30). In summary, adequate supplies of water need to be available, and water needs to be used for personal hygiene (32, 33). Furthermore, increased water availability not only facilitates better hygiene and cleanliness but releases time needed for these activities to take place (14).

Environmental Improvements: Sanitation & Trachoma

Access to excreta disposal facilities is understood to have an indirect effect upon the risk of trachoma by reducing feces in the environment, which in turn reduces breeding media for the *Musca sorbens* fly, a likely vector of *Chlamydia trachomatis*. Existing evidence of the role of sanitation in trachoma control, however, remains limited.

The authors of an earlier systematic review of the evidence linking environmental improvements with trachoma control described the historically-observed association of flies with trachoma (14). The potential of flies for trachoma transmission was more clearly demonstrated through a study in the Gambia that elucidated the relationship between trachoma and sanitation. In this study, 1 village from each of 2 pairs of villages was assigned to fly control using insecticides for 3 months, and it was found that fly control reduced Muscid flies by 75%, reduced fly-eye contact by >95%, and decreased new prevalent trachoma cases by 75% (34). A subsequent ecological study provided strong evidence implicating the fly *Musca sorbens* as a vector of trachoma in the Gambia (29). The authors posited, based on the knowledge that these flies breed in human feces but were not observed to emerge from pit latrines, that ending open defecation through consistent use of pit latrines may effectively remove the flies' larval habitat from the environment (29). An additional study then found that flies developed in the feces of other animals, cattle and dogs in particular, but that human feces supported the production of large quantities of flies and even produced more and better quality flies compared to other breeding media (35). The authors concluded that by isolating human feces, sanitation could reduce trachoma transmission.

In spite of this understanding, there have been only two randomized, controlled trials examining the effect of latrine provision on trachoma (36). In The Gambia, the first trial found that fly catches from children's eyes were reduced by 88% by insecticide spraying and by 30% by household latrine provision and that the mean prevalence in trachoma was reduced by 56% by spraying and by 30% with latrines (37). The authors concluded that the eye-seeking fly, *M. sorbens*, is a vector of trachoma, and that latrine provision reduced fly-eye contact and could be promoted for the control of trachoma (37). A second, more recent trial in Ethiopia then sought to examine the impact of intensive latrine promotion on the re-emergence of trachoma. The authors of this study found that latrine promotion, including subsidized provision of latrine slabs, increased coverage and use, but at 24 months could not demonstrate a difference in the prevalence of ocular *C. trachomatis* infection and active trachoma in children (38). A subsequent ecological, cohort analysis restricted to communities in the trial's latrine promotion arm found that for each 10% increase in the proportion of households with evidence of recent latrine use at 12 months there was 2.0% decrease in community prevalence of ocular *C. trachomatis* infection over the subsequent year, but no association was found between community latrine coverage and the change in prevalence of active trachoma (TF/TI) (39).

These studies were included in a recent meta-analysis examining the effect of water, sanitation, and hygiene on trachoma prevention. Based on 26 studies, Stocks *et al*. found that sanitation access was associated with both active trachoma (OR 0.85, 95%CI 0.75--95) and, based on 7 studies, *C. trachomatis* infection (OR 0.67, 95%CI 0.55-0.78) (30). When this measurement considered actual sanitation use in 6 studies, a protective but non-significant association with active trachoma was detected (OR 0.86, 95%CI 0.57-1.15). This recent meta-analysis and the earlier review both highlighted the limited quality of the available evidence (14, 30). Emerson *et al.* also noted that the finding of a protective association of household sanitation with trachoma prevalence holds the unreasonable implication that flies do not move between households and emphasized the relevance of community-wide protection (14). The authors of the meta-analysis also emphasized the need for further research to characterize the relative importance for trachoma control of sanitation access at the household level in contrast to sanitation coverage in the community as a whole (30). As such, an examination of the effect of community sanitation coverage upon individual presence of trachoma is warranted.

Chapter 3 - Soil-transmitted Helminth Infections

The four main species of soil-transmitted helminth (STH) infections, or geohelminths, include: the roundworm, *Ascaris lumbricoides*; the whipworm, *Trichuris trichiura*; and the hookworms, *Ancylostoma duodenale* and *Necator americanus*. Infection with more than one species within a single individual is common, and as a result they are often grouped together. It is currently estimated that more than 2 billion people are infected with these parasites (40). Like other neglected tropical diseases, soil-transmitted helminth infections contribute to the cycle of poverty. Chronic infection results in a number of detrimental public health, economic, and educational outcomes, including: Impaired physical and cognitive development, school absenteeism and poor performance, reduced work productivity among adults; adverse pregnancy outcomes; and possible increased susceptibility to malaria, tuberculosis, and HIV (41).

Occurrence

These parasitic nematode worms cause infections in humans through exposure to eggs or larvae that thrive in warm, moist soils of the tropics and subtropics, particularly in poorer areas with inadequate access to water and sanitation. Climate is an important determinant of transmission as eggs and larvae require suitable conditions in the environment for development prior to reaching the infective stage (41). The highest STH prevalences are found in east Asia and the Pacific islands and sub-Saharan Africa (42).

Identification and Clinical Signs

STH infections rarely cause death, so the burden of disease results from the chronic nature of the infections and their insidious effects (43). In turn, morbidity is related to the burden of infection, the number of worms residing within the host, and the health of the host (44). The highest intensity infections are most common in children (41).

Clinical features of STH infections involve two phases: symptoms resulting from the migratory stages of the larvae through the skin or internal organs and acute or chronic symptoms resulting from residence of adult worms within the gastrointestinal tract (41).

Most roundworm infections are symptomless, but respiratory conditions, such as verminous pneumonia can occur in response to inflammation resulting from antigens to migrating *Ascaris* larvae in the lungs (41). Penetration of the skin by hookworm larvae may result in "ground itch," a local rash on the hands and feet, and passage of the larvae through the lungs may cause pneumonitis (41). Whipworm eggs hatch in the intestine, so there is no migratory process outside the intestine.

Once established in the intestine, the extent of clinical manifestation depends on the intensity of infection (41). An intense roundworm infection in the small intestine may result in digestive disorders, nausea, abdominal pain, vomiting, restlessness, and disturbed sleep, and adult worms can be passed in feces or by mouth (44). Nutritional deficiencies and growth failure can result, while aggregation of worms in the ileum in young children can cause obstruction with clinical signs and symptoms of peritonitis (41). In adults, whipworm infections are often symptomless, except for some diarrhea and abdominal pain, but malnourished children with heavy infections can suffer anemia, chronic dysentery, and prolapse of the rectum (44). Hookworm infection is frequently symptomless, but blood loss resulting from parasite attachment to intestinal walls may lead to iron-deficiency anemia and its clinical manifestations, such as weakness and debility (41, 44).

Definitive diagnosis of STH infection depends on the identification of eggs in fecal samples. Hookworm eggs appear identical on microscopic examination, so an anthelminthic drug must be taken and expelled adult worms identified or eggs must be cultivated until the infective larval stage is reached (44).

Etiology and Epidemiology

Humans are considered the reservoir of these parasites (17). The distribution of the disease within community is over dispersed, meaning that most individuals are infected with a few worms, while a small number of people have very intense infections, through natural predisposition, and who are in turn both point sources of contamination and at greatest risk of disease (43). The prevalence of roundworm and whipworm usually peaks prior to 5 years of age, plateauing afterwards, while intensity peaks between 5 and 15 years of age and drops off afterwards (43). Hookworm prevalence peaks in adolescence or early adulthood, and intensity increases until adulthood and then plateaus (43). While co-endemicity and co-infection are common, the STH have distinctive epidemiologic patterns resulting from differences in transmission and development (44).

Lifecycle and Transmission

The STH lifecycle begins when eggs are deposited on the soil after open defecation or the application of human feces as fertilizer. The eggs of *Ascaris* and *Trichuris* must develop in warm, moist soils to become infective, while hookworm eggs mature into motile larvae that seek out contact with human skin.

Environmental conditions, such as atmospheric humidity, temperature, rainfall, altitude, and soil type are important determinants of prevalence because of their impact on STH lifecycles (45). Ideal conditions for roundworm egg development are moist, shady soil at 22-32°C, under which approximately 75% of eggs will become infective within a minimum of 10-15 days (44). Infective roundworm eggs can survive for up to 7 years (44). Whipworm eggs require 2-5 weeks to develop into the infective stage, and development times are inversely related to temperature: 4-6 months at 15°C; 3-4 weeks at 26°C; 17 days at 30°C; and 11 days at 35°C (44). Whipworm eggs are less resilient than roundworm but may survive for several months in suitable conditions (44). Hookworm eggs hatch into first stage larvae within 24-48 hours under suitable conditions, and these larvae then undergo two moults outside the human body to become the infective 3rd stage (44). Larvae may survive up to 15 weeks, but normally survive for 3-6 weeks (44). Optimal conditions for hookworm development involve shady, moist soils at 28-32°C for *N. americanus* and 20-27°C for *A. duodenale*, and not below 10°C or above 40°C (44). Soil type may be a major source of variation in STH prevalence. Hookworms reportedly prefer light sandy loam soils with adequate but not excessive moisture that facilitate movement and survival of the larvae, while roundworm prevalences are highest in areas of fine silts and clays (44).

The mature eggs of *Ascaris* and *Trichuris* and *Ancylostoma* larvae are transported to the mouth on hands and fomites, in dirt, and on contaminated raw vegetables (41). Ingested whipworm eggs release larvae that feed and grow in the small intestine before taking up residence to become mature adults in the large intestine within about 12 weeks (41, 44).

Ascaris larvae must undergo a migratory stage outside the intestine, after which they enter the lungs and subsequently return to the gastrointestinal tract by passing over the epiglottis, and they develop into egg-laying adult worms within 9-11 weeks of ingestion (41). Waterborne transmission is not a significantly important mode of transmission compared to yard or field transmission (44). Hookworm larvae most commonly infect humans by penetrating the skin of the feet, after which they access the host's circulatory system to enter the lungs, pass over the epiglottis to enter the gastrointestinal tract, where they develop into egg-laying adults in about 5-9 weeks (41). An important feature of the STH lifecycle is that they do not reproduce within the host, so each worm is the result of a single infection (41).

Feachem *et al.* described three contexts for transmission with the importance of each determined by the lifecycle of the respective organism (44): Domestic transmission resulting in household areas contaminated by small children; transmission to persons working in fields fertilized by human excreta; and transmission through consumption of raw contaminated vegetables. As a consequence of their lifecycle, hookworm eggs and larvae are found primarily in defecation areas or where feces are applied as fertilizer, and most infections occur in these same locations (44). Roundworm infection clusters within households and families, as most transmission occurs in and around the house, resulting from contamination of the soil by defecating small children (44).

Control and Prevention

Rather than eliminating parasites, large-scale control efforts focus on eliminating morbidity from high worm burdens through regular treatment to avert the consequences of chronic infection, such as impaired growth, poor fitness and nutritional status (40, 41).

The WHO recommends periodic administration, once or twice annually based on initial prevalence among school-age children, of albendazole (400mg) and mebendazole (500mg) to at-risk populations (40), including:

- preschool-age children;
- school-age children;
- women of reproductive age, including pregnant women and lactating mothers;
- and other adult groups with high exposure.

The anthelminthic drugs albendazole and mebendazole are both effective against roundworm in a single dose, but albendazole is more effective than mebendazole against hookworms (41). A single dose of albenazole is less effective in many cases of whipworm infection, and, for both hookworm and whipworm infection, several doses of drugs are often needed (41).

While current drugs remain effective, the rise of drug resistance to anthelminthics in livestock nematodes raises concerns about the possibility of drug resistance developing in human species (41). Another challenge with mass drug treatment is that, without reducing fecal contamination of the environment, “reworming” occurs quickly after treatment and infection levels can return to pretreatment levels (41). Improved sanitation and hygiene knowledge may serve to maintain the low intensities and prevalences created by the mass chemotherapy (44).

Without improvements in sanitation and excreta disposal behaviors to reduce levels of fecal contamination, re-infection after treatment remains likely through continued environmental exposure to infective eggs and larvae. It is widely recognized that the long-term effectiveness of de-worming efforts through mass treatment will be jeopardized without concurrent improvements to sanitation and excreta disposal behaviors (2, 43, 46-49). Despite this, the current WHO strategy for the elimination of STH as a public health problem in children decried the limited resources to sustain sanitation infrastructure in countries where it is needed and pushed off improved access to sanitation as a long-term strategy (40). In response to similar shortcomings in proposed NTD control strategies, there has been a call for greater inter-sectoral collaboration between the water, sanitation, and hygiene (WASH) sector and groups working towards NTD control (10).

A recent systematic review and meta-analysis of 36 studies found that there was a significant protective effect of household access to sanitation upon individual risk for any of the soil-transmitted helminths combined, considering either household access or usage (50). The authors kindly provided the results of their exhaustive search and the metrics for inclusion or exclusion. The authors had focused on individual level data and not upon the effect of intervention coverage and use, so these articles were not included. Of 162 publications deemed relevant, 6 articles provided information on latrine coverage (4%). In

Bangladesh, Khan *et al*. described the lack of impact on STH prevalence of communal latrine provision, compared to pit latrines in a control community, which they attributed to continued open defecation (51). In former Zaire, Tshikuka *et al*. examined predictors of AL infection in children under-16 years in urban communities, stratified by socioeconomic status (SES), and found open defecation to be a risk factor for AL in 2 lower SES communities, but not in a higher SES community (52). Curtale *et al*. measured prevalence of STH in urban and rural communities of an area of Egypt and attributed higher prevalences and intensities of STH infection in urban areas to poorer living conditions and sanitation standards (53). Sorensen *et al*. investigated STH prevalence and intensity in relation to sanitation availability in rural tea plantations of Sri Lanka and found, with increased sanitation, lower HW and TT intensities but lower AL intensity only in lower density communities (54). Eve *et al*. studied prevalence and intensity of STH infections among rural populations in three districts in Amazonas state, Brazil and found that the district with highest proportion of open defecation also had highest mean HW and TT intensities but not AL (55). Mangali *et al*. compared the prevalences of STH infections with latrine coverage between 5 villages in Indonesia and found an inverse relationship between coverage and HW prevalence but no relationship with AL or TT (56).

Beyond the varied results of each study, the finding of so few studies overall describing the relationship of community sanitation with STH infection is interesting in itself because the importance of greater coverage throughout the community, as opposed to reaching just a small cluster or scattering of households, has long-been recognized and further studies indicated (57). As such, there is a significant knowledge gap regarding the effect of community sanitation coverage on soil-transmitted helminth infections.

Chapter 4 - Sanitation

The World Health Organization (WHO) defines sanitation as the provision of facilities and services for the hygienic disposal of human excreta (58). “Hygienic” meaning that the facilities prevent any immediate or subsequent human contact with excreta. Attempting to characterize human excreta disposal requires a broad range of options. These options range from infrastructural technologies, such as flush toilets connected to networked, piped sewerage systems and basic pit latrines or “privies,” to the practice of open defecation, which by definition involves no facility, only deposition of feces on the ground or into surface waters directly or wrapped and thrown away.

For clarity in their monitoring efforts towards the Millennium Development Goals (MDG), the WHO and UNICEF classified all excreta disposal options within two broad categories: improved and unimproved (59). Improved sanitation includes access to: a flush toilet, a piped sewer system, a septic tank, a pit latrine, or a composting toilet. Unimproved sanitation refers to options that do not ensure hygienic disposal of human excreta, including: a toilet that flushes to a location in the immediate environment other than a sewer, septic tank, or latrine; a pit latrine with an inadequately sealed pit; a bucket; a hanging toilet; or open defecation. Shared facilities are considered to be unimproved sanitation. Looking ahead, post-2015, the WHO has adopted more concise definitions for “basic” sanitation facilities at home as those that effectively separate excreta from human contact and ensure that excreta do not re-enter the immediate household environment (60). Basic sanitation includes all of the following, if the facility is shared among no more than 5 families or 30 known persons:

- A pit latrine with a superstructure, and a platform or squatting slab which fully covers the pit without exposing the pit content other than through the squatting hole or seat. The platform or slab should be constructed of durable, easy to clean material (concrete, logs with earth or mud, cement, etc.). A variety of latrine types can fall under this category, including composting latrines, pour-flush latrines, and VIPs.
- A toilet connected to a septic tank or sewer (small bore or conventional).

Among these, the most basic on-site sanitation option is the pit latrine, essentially a superstructure for shelter and privacy built over a hole in the ground with an adequate cover (61). Gravity does the work to collect and store excreta in the pit.

Sanitation and Health

When we talk about the global sanitation crisis, what is really meant is a global excreta crisis (62). Excreta-related diseases cause a significant amount of morbidity and mortality in poor and malnourished populations, and the capacity for human excreta to cause disease means that its collection, transport, treatment, and disposal are critical for the protection of our health (44). More than 50 human pathogens, such as viruses, bacteria, protozoal cysts, and helminth eggs, can be transmitted from human excreta (44). The exact pathway of transmission depends on the setting and agent but may include direct transmission on fingers, indirectly on food or fomites, in water or soil, or any other way in which infective excreta may be ingested, inhaled, or contacted (61).

The importance of adequately isolating feces from subsequent human ingestion for disease control has been recognized since Dr. John Snow established water as the mode of transmission for cholera in London in the mid-19th century. Yet, since Snow's time, little rigorous evidence of the relationship between sanitation and health has been established (63, 64). In the latter part of the 20th century, as justification for the declared International Drinking Water Supply and Sanitation Decade (1981-1990), disease control efforts focused on child survival and accordingly targeted diarrheal diseases as the metric of impact for interventions (65). Focused on this outcome, early reviews emphasized the scarcity and poor methodological quality of most studies and the need for better evidence of a health impact evaluation of improved water supplies and excreta disposal facilities (63).

Despite methodological problems, subsequent reviews of the impact evaluation literature have compiled evidence that: handwashing, water quality and supply, and sanitation have a significant protective effect against diarrheal diseases; improvements of water quality at the source provide few gains; and that combined interventions do not have a greater impact than any single intervention (66-75). Furthermore, perhaps the most surprising finding from these reviews is that despite a, or perhaps because of its, fundamental role in isolating human feces from the environment, excreta disposal appears the least studied intervention within the water, sanitation, and hygiene sector, at least with regards to diarrheal morbidity.

While the bulk of the evidence is related to diarrheal diseases, sanitation provision has been directly linked to NTDs, such as trachoma, STH infections, and schistosomiasis, because of its role in containing excreta, and indirectly linked to acute respiratory infections and under-nutrition, through their relationship to diarrheal disease (2). More recently, based on limited impacts of nutritional and disease control interventions to achieve normal growth in children living in poverty, environmental enteropathy (EE) has been suggested as the mediator, rather than diarrheal disease, in the relationship between infection and under-nutrition (76, 77). Environmental or tropical enteropathy, also known as environmental enteric dysfunction, is a sparsely-characterized subclinical disorder of the gut that results from “prolonged and persistent” ingestion of fecal pathogens by young children living in extreme poverty (77). Further understanding of the impact of EE in early life on subsequent physical and cognitive development is needed, but the basic function of sanitation and hygiene in isolating feces from human contact indicates that these interventions may play more of a direct and critical role in prevention of EE and improved child development than previously thought (76).

Community Sanitation Coverage and Household Sanitation Access

Much of the evidence of the relationship between sanitation and health outcomes is based on assessment of household access to sanitation and fails to adequately capture the domains of disease transmission beyond the household, the relative importance of which depends on the disease and its epidemiology (78). Few studies examine sanitation coverage levels and disease. Some that have, however, have found significant associations between community sanitation coverage, measured as the proportion of households in the community with access to a latrine, and improvements with respect to different disease outcomes, including diarrhea, STH infection, and weight-for-height (79-82).

An important policy question regards the relative effects of sanitation, measured as community coverage or household access, and similarly what level of sanitation coverage is needed in order to bring about an improvement in health outcomes (79). Despite the fundamental nature of this question, to-date the evidence employed as the basis for decision-making is extremely limited. For example, seventy-five percent is the oft-cited level (83), which appears to be derived from one of the earliest studies examining community sanitation coverage and health. Bateman *et al*. used demographic and health survey data from Guatemala to examine the relationship between cluster sanitation coverage and individual water and sanitation access and stunting in children (84). They found that community sanitation coverage below 75% was associated with a higher risk of stunting than was lack of individual access to a toilet. The authors isolated 75% as their cutoff point for dichotomizing community coverage through an exploratory analysis, calculating odds ratios for each of 21 cutoff points (5 percent increments from 0 to 100 percent sanitation in the cluster) and selecting the level with the highest odds ratio. Based on their finding the authors asserted that community measures of sanitation are better indicators of health than individual access. Despite this suggestion, few other studies have specifically examined the relationship between sanitation and health outcomes in this way.

Community-based Sanitation Interventions

A similar understanding of the importance of the community is now recognized by programs aiming to increase uptake of sanitation, as they realize that households may not be the most cost-effective point of intervention for health messaging (85). Community-led total sanitation (CLTS) is a mobilization approach aimed at ending open defecation through community-wide action. It was initially developed and employed in Bangladesh (86), but it is now being widely implemented throughout the world. The approach typically involves: mobilization of local government, institutions, community organizations, and NGOs; community analysis using participatory rural appraisal tools; generating demand for toilets and hygiene through shame and disgust; no or limited subsidies for household toilets; diversity in technology; and the provision of a budget to districts or communities for software aspects (87). Despite the extent to which CLTS is being implemented, much of the evidence is based on programmatic reports, or gray literature, and there have been no systematic reviews of peer-reviewed studies on the effectiveness and impact of these programs (88). The findings of a systematic review of the gray literature on CLTS emphasized the importance of: monitoring and evaluation mechanisms to sustain and scale-up activities; follow-up activities after triggering; and harmonized approaches among local, national, and international organizations based on national CLTS strategies (88). The effect of behavioral techniques used during demand generation or “triggering” events on the sustainability of behavior change has not been assessed (88).

Environmental Conditions and Community Sanitation

Just as context is an important consideration for studies of disease, environmental conditions, such as soil conditions or land cover, and social conditions, such as population density or distance to roads, may have a profound effect on household uptake or maintenance of sanitation and, as a result, the achievable and sustainable levels of community sanitation.

From an engineering perspective, it is recognized that environmental and geographical factors, like geology or climate, may influence the feasibility of introduced sanitary solutions (89). However, adverse conditions for latrine construction may also prevent, delay, or dissuade a household from constructing their own latrine in response to a community-based sanitation intervention, like community-led total sanitation. For example, the authors of a study in Ghana reported that soil conditions were an important barrier of adoption that delayed or postponed construction, even after intention to build a latrine was established (90). Similarly, in Tanzania respondents in rural households reported soil condition to be a constraint to building a latrine, and weak soil and latrine collapse were reported by focus groups as main problems hindering sanitation coverage in Kenya (91, 92).

The extent of vegetation or land cover near a community may influence household adoption of sanitation in two ways. Greater availability of vegetation may facilitate adoption of sanitation because local materials, such as branches and mud, are used to construct the pit latrines superstructures and slabs (62). Alternatively, decreased land cover, like bushes, was reported in Tanzania as a motivation to build latrines because there was less privacy (62). Similarly, household clustering and deforestation were acknowledged as factors contributing to reduced open defecation in Ethiopia (93).

Just as local geographic conditions may deter or incite initial adoption of household sanitation, environmental factors may strongly influence the durability of built latrines, particularly the rudimentary ones constructed in response to CLTS activities, or deter households from maintaining or replacing previous latrines. An evaluation of latrine sustainability in The Gambia described how collapse of the pit was the primary reason for latrines becoming unusable (94). Simms *et al.* described how the desire to build latrines “out of sight” and not in valuable farmland led to their construction in areas with a higher water table or prone to flooding, which contributed to latrine damage. During particularly heavy rains, the sandy soil in the study area became liquefied and flowed "like quicksand," causing cement latrine slabs to tip or sink into the ground under their own weight. Even soils that appear self-supporting when initially excavated, like clays or silts, may lose this property over time due to changes in soil moisture (95). In addition to weak soil structure, flooding in low-lying areas during the rainy season was also reported to be a hindrance to sanitation coverage in Kenya (91). Water filled latrines, causing them to overflow and often collapse, and the difficulty and expense of rebuilding latrines after the rains was a disincentive, leading families to prefer open defecation (91).

Alternatively, local social conditions may actually increase initial demand for sanitation and incite households to construct a latrine in response to conditions becoming more adverse to open defecation. For example, increasing population density in and around the community and decreasing availability of secluded areas for defecation have been reported as motivations for increasing adoption of household sanitation in Benin (96). In Kenya, the loss of privacy from increasing population density was a motivation to build latrines (91). Local changes tied to development, such as increases in population, occupational diversity, regional integration, and proximity to roads, may not only reduce availability of open defecation sites but also increase need for privacy in the face of increased crime or newcomers, which increases latrine adoption (96).

Information on numerous environmental and social conditions is now widely available, and its accuracy and breadth of content should only increase in the future. Studies in disease ecology and public health have employed geographic information systems incorporating this information in studies of NTDs, such as Chagas disease and STH infection (97-99). The application of these approaches, utilizing environmental and social conditions, to study contextual influences on distribution of community sanitation may prove a promising approach for identifying areas at risk of poor sanitation that need alternate or additional sanitation interventions.

Chapter 5 - Association of Community Sanitation Usage with Active Trachoma among Children in Amhara Region, Ethiopia[1]

Abstract

Background: Community sanitation is a component of the WHO-promoted "SAFE" strategy for trachoma control. This study aimed to estimate the association between community sanitation usage and active trachoma prevalence among children, aged 1 to 9 years, in Amhara Region, Ethiopia, following 5 years of SAFE implementation.

Methods: Prevalence of trachoma and household pit latrine usage were measured between 2011 and 2014. During surveys, enumerators observed indicators of latrine use; these data were aggregated into a measure of community sanitation usage, the proportion of households with a latrine in use. Residents were examined for clinical signs of trachoma. Multilevel logistic regression was used to estimate the association between community sanitation usage and active trachoma, indicated by trachomatous inflammation, follicular (TF) and/or intense (TI).

Results: Prevalence of active trachoma was estimated to be 29% (95%CI 28--30%). Mean community sanitation usage was 47% (95%CI 45--48%). Increased community sanitation usage was associated with decreased prevalence odds of active trachoma compared to usage <20% (20--<40%: OR 1.06, 95%CI 0.78--1.44; 40--<60%: OR 1.01, 95%CI 0.74--1.37; 60--<80%: OR 0.76, 95%CI 0.57--1.03; ≥80% OR 0.67, 95%CI 0.48--0.95),

[1] This chapter is a manuscript prepared for submission to a peer-reviewed journal. As such the structure, format, and length are in keeping with journal requirements. Use of the plural pronoun 'we' refers to members of the dissertation committee and other co-authors on this submission.

summarizing across household water and sanitation conditions and adjusting for individual, household, and community factors.

Conclusions: Despite 5 years of SAFE, active trachoma remains not controlled among children aged 1 to 9 throughout this region. The relationship between community sanitation usage and active trachoma highlights need for continued efforts to encourage high levels of adoption and support sustained use of sanitation.

Keywords: trachoma; Neglected Tropical Diseases; sanitation; SAFE; multilevel modeling; Ethiopia

Introduction

Globally, trachoma remains the leading infectious cause of blindness. It is estimated that approximately 1.2 million people are blind because of this disease and a further 1.7 million have low vision (100). It was recently estimated that 40.6 million people suffer from active trachoma, while 8.2 million have trichiasis, the blinding stage of disease (12). Twenty-nine countries of the African region account for 77% of the global population estimated to live in endemic areas, and Ethiopia is the country most affected by trachoma worldwide (101). As with other Neglected Tropical Diseases (NTDs), trachoma is predominantly found in resource-poor, rural communities in low-income countries (13, 15). Trachoma afflicts the most deprived people in the world, leading to disability, dependency, and further poverty (14).

The World Health Organization (WHO) endorses SAFE, a comprehensive strategy to treat and prevent trachoma combining four control measures based on epidemiologic and biologic evidence: Surgery for the correction of trichiasis, Antibiotics through mass drug administration (MDA) to reduce infection reservoir in the community, Facial cleanliness to reduce transmission, and Environmental improvements, such as control of flies through sanitation and access to water, to further reduce the potential for transmission (26, 27).

Trachoma control, based on SAFE, in Amhara National Regional State was scaled-up from a pilot in four *woreda* (Ethiopian administrative units equivalent to districts) in 2001 to cover the entire state by 2007 (102, 103). Amhara Region suffers the highest burden of active trachoma within Ethiopia (104). With the current study, we aimed to estimate the association of the proportion of households in a community with latrines in use with active trachoma prevalence among children, aged 1 to 9 years, in Amhara, Ethiopia, following 5 years of SAFE implementation. We hypothesized that higher community sanitation usage will be associated with lower prevalence of active trachoma.

Material and Methods

Study overview and subjects

SAFE impact surveys were conducted by the Amhara Regional Health Bureau and The Carter Center's Trachoma Control Program to provide population-based *woreda* estimates of trachoma prevalence; quantify SAFE uptake; estimate proportions of households with water and sanitation access; and determine control strategies according to WHO guidelines (18). *Woreda* became eligible, in order of SAFE implementation, if a pre-SAFE survey had been conducted, monitoring data had been collected, and at least five rounds of annual azithromycin MDA had occurred, allowing a minimum of 6 months from the last round of antibiotic distribution.

For the current study, data were combined from five surveys conducted in distinct areas of Amhara between 2011 and 2014. The first survey was conducted in South Gondar zone between June and August 2011. The methods and results of this study have been described previously (105, 106). The second survey was conducted in North Gondar and West Gojjam zones between May and June 2012. The next three surveys were conducted in eastern Amhara from December 2012 to January 2013, in western Amhara from June to July 2013, and in eastern Amhara from January to February 2014.

All surveys used a multi-stage cluster random sampling methodology to estimate *woreda* prevalences of trachomatous inflammation-follicular (TF). Villages, or *gott*, are the smallest administrative unit with population data available and were primary sampling units. Within each *woreda*, *gott* were systematically selected from a geographically-ordered line listing probability proportional to population size. Within *gott*, smaller administrative units of approximately 40 households, called development teams (DT), were used as segments for a modified segment design (107, 108). Development teams were listed upon arrival in the community with an appropriate *gott* representative, who then drew numbers from a hat to select DTs to be surveyed. In *gott* of 40 households or less, the entire *gott* was surveyed. For the current study, selected DTs were considered clusters, the immediate geographic area of residence of participants.

In selected clusters, *gott* leaders were interviewed for community information. All consenting residents of all households were examined for clinical signs of trachoma, according to WHO guidelines (18). Each eye was examined separately by a trained trachoma grader using a 2.5x binocular loupe for the presence or absence of all five clinical signs of the simplified trachoma grading system (19). Heads of household were interviewed for demographic, socioeconomic information, and knowledge and practices regarding trachoma, water, sanitation, and hygiene. Visual inspections were made of household latrines and handwashing stations. Responses were recorded electronically using tablet computers operating on the Android platform (Google Inc.; Mountain View, CA, USA), and questionnaires at the community, household, and individual levels were linked (109).

Measures

The exposure, community sanitation usage, was calculated as the proportion of households within the cluster with a latrine in which feces were observed in the pit and to which there was a defined path (110). The outcome was a dichotomous measure for presence of active trachoma based on the WHO simplified grading scale (None vs. TF and/or TI) (18).

Covariates

At the individual level, covariates included: Age in years, centered at 5; sex; school attendance (children <6 years were assigned a no response); ever receiving antibiotics during MDA; number of times received antibiotics during MDA, 0-5; absence of ocular or nasal discharge on child's face. Household access to water was dichotomized <30 min or not, based on asking how long it took to fetch water for bathing. Indicators were created for presence of a pit latrine and presence of a pit latrine in use (defined above). Household wealth was indicated by ownership of radio, television, mobile phone, metal roof, and access to electricity. Any trachoma prevention knowledge was indicated by prompted reporting of ≥1 forms of trachoma prevention. A categorical variable was created for the highest level of education completed by respondents in the first survey or any household member in subsequent surveys. Cluster wealth was calculated as the mean total wealth indicators reported by households. Cluster exposure to MDA was calculated as the median times reported by all residents of receiving antibiotics during MDA. A raster surface for Ethiopia with 2011 population density per square kilometer was generated using the Oak Ridge National Laboratory's LandScan (111). Density values were extracted for each cluster in ArcMap 10.1 (ESRI, Redlands, CA, USA). Density was evaluated as quintiles, quartiles, tertiles, a dichotomous indicator, and a continuous measure. Presence of a health post, health center, or hospital was dichotomized as the presence of any health facility.

Analyses

Means and frequencies were estimated with confidence intervals across categories of community sanitation usage, accounting for study design and unequal selection probabilities. Multilevel logistic regression was used to estimate the association between the proportion of households in each cluster with a latrine in use and active trachoma among children aged 1 to 9 years. Potential confounders were identified and assessed based on literature review, authors' knowledge, evaluation of directed acyclic graphs (112, 113), bivariate analyses, and preliminary modeling.

Generalized linear mixed models were fit, specifying random intercepts for cluster and households nested within clusters. Robust standard errors were requested to account for clustering within *woreda*, and adaptive quadrature with 8 integration points was used. Sampling weights based on inverse selection probability for cluster, household, and individual were incorporated. Individual and household weights were scaled to sum to the household and cluster sample size, respectively (114), which by design equaled effective cluster sample size. Participants not aged 1 to 9 years were assigned an individual weight of 0.0001. An empty model was fit to measure between-cluster and between-household variance, and conditional intraclass correlation (ICC) and median odds ratios (MOR) were calculated (115, 116). Multiplicative interaction of the association of community sanitation usage with active trachoma by household latrine use and water access was evaluated with likelihood ratio tests. All described analyses were conducted using Stata 13.1 (StataCorp LP, College Station, TX, USA).

Survey protocols were approved by Emory University Institutional Review Board (079-2006) and Amhara Regional Health Bureau. This secondary analysis was exempt from additional review.

Results

The combined dataset linked information on 233 363 individuals, from 56 169 households, in 1510 clusters throughout Amhara (Figure 5.1). Of 68 961 children aged 1 to 9 years, 62 869 (91%) in 35 977 households had eye examination results. Among 6092 children without eye examination results, 4864 (80%) were reported to be out, traveling, or at school during the survey, 734 (12%) refused the examination, and 494 (8%) did not have a reason provided.

Table 5.1 describes individual, household, and community characteristics of children aged 1 to 9 years examined for signs of trachoma, overall and by community sanitation usage category. Almost all factors were significant, most likely because of the large sample.

Children in communities with lower sanitation usage had indicators of poorer hygiene, more impoverished and rural living conditions, and less education and healthcare, compared to children in communities with higher sanitation usage. Of children's households, 61% (95%CI 57--66) and 74% (95%CI 69--78%) had access to water for bathing within 30 min in communities with lowest and highest sanitation usage, respectively. Households in communities with lower sanitation usage had a mean of 0.74 indicators (95%CI 0.68--0.79) compared to 1.72 indicators (95%CI 1.58--1.87) in communities with higher sanitation usage.

SAFE exposure followed patterns of community sanitation usage. Children in communities with lower sanitation usage were less likely to have ever received antibiotics during MDA (74%, 95%CI 72--77%) than children in communities with higher sanitation usage (85%, 95%CI 83--88%). Trachoma prevention knowledge was reported by more than half of households (61%, 95%CI 60--62%), but knowledge was lower in communities with less sanitation usage. Where latrines were present, latrine usage was high. Among households, 52% owned a pit latrine (95%CI 50--53), the primary form of sanitation recorded, of which

93% were considered in use (95%CI 92--93). The mean age of latrines as recorded in three surveys was reported to be 2.59 years (95%CI 2.49--2.70). Median reported times received antibiotics for all community residents was 2.37 (95%CI 2.28--2.47) and 2.91 (95%CI 2.80--3.02) among communities with low and high sanitation usage, respectively.

In 1510 clusters, mean community sanitation usage was 47% (95%CI 45--48%) and ranged from 0% in 106 clusters (7%) to 100% in 25 clusters (2%). Community sanitation usage was modeled as five equally-sized categories to balance fit and interpretability and represent possible thresholds in the relationship between sanitation and trachoma prevalence (Figure 5.2). Prevalence of active trachoma in children aged 1 to 9 across surveyed areas of Amhara, following 5 years of SAFE, was estimated to be 29% (95%CI 28--30%) (Table 5.1).

Table 5.2 presents results from a series of models of the association of community sanitation usage with active trachoma, sequentially controlling for selected individual, household, and community factors, and adjusting for survey. Community sanitation usage of 60--<80% and ≥80% were associated with lower prevalence odds of active trachoma compared to usage of <20% (Model 1: 20--<40% OR 1.03, 95%CI 0.76--1.39; 40--<60%, OR 0.91, 95%CI 0.66--1.26; 60--<80%, OR 0.67, 95%CI 0.47--0.97; ≥80%, OR 0.51, 95%CI 0.35--0.73). Adjustment for child's age and sex (Model 2) and household water access and latrine use (Model 3) did not meaningfully change estimated odds ratios. After inclusion of household wealth indicators and education (Model 4), an aggregated community wealth measure (Model 5), and community median times received MDA, the pattern remained the same but was attenuated towards null (Model 6: 20--<40% OR 1.12, 95%CI 0.81--1.55; 40--<60%, OR 1.06, 95%CI 0.74--1.52; 60--<80%, OR 0.84, 95%CI 0.55--1.26; ≥80%, OR 0.68, 95%CI 0.45--1.04).

Excluding any predictors, variances between households and clusters were estimated to be 0.68 (SE 0.08) and 2.22 (SE 0.20), respectively. MOR comparing children of different households from different communities was calculated to be 5.07, while that comparing children of different households from the same community was calculated as 2.19. Variance did not meaningfully change across models. Residual heterogeneity between clusters was of greater relevance than community sanitation usage. Based on Model 6, MOR showed that residual heterogeneity between children of different communities reflected, on average, almost six-fold increases in individual odds of active trachoma (MOR 5.82).

Magnitude of association between community sanitation usage and active trachoma was found to vary significantly by household latrine use and water access ($P_{interaction}<0.0001$). No clear pattern in stratified odds ratio estimates and confidence intervals was discerned, so summary estimates, weighted by population in strata of household latrine use and water access, were reported in Table 5.3 by community sanitation usage (20-<40%: OR 1.06, 95%CI 0.78--1.44; 40-<60%: OR 1.01, 95%CI 0.74--1.37; 60-<80%: OR 0.76, 95%CI 0.57--1.03; ≥80% OR 0.67, 95%CI 0.48--0.95).

Discussion

Our study shows that increasing the proportion of households in a community with latrines in use may be protective against active trachoma amongst children aged 1 to 9 years, independent of whether or not a child's household had a latrine in use or better access to water. Clear evidence was not found of multiplicative interaction of the association of community sanitation usage with active trachoma by household latrine use and water access. Increased community sanitation usage was associated with lower prevalence odds of active trachoma, after controlling for individual, household, and community factors.

Environmental improvements are considered definitive interventions for trachoma based on its elimination from all developed cities in the world (16). Studies in The Gambia clarified evidence of the relationship between feces in the environment and trachoma, identifying as a vector the fly, *Musca sorbens*, that breeds in openly-deposited human and animal feces but not in pit latrines (29, 34, 35). A randomized, controlled trial then found that fly catches from children's eyes and mean active trachoma prevalence were reduced through latrine provision, though the latter effect was not statistically significant (37). Another randomized, controlled study to measure the effect of latrine promotion on re-emergence of trachoma after MDA failed to find a significant relationship between increased community sanitation and prevalence of active trachoma or *Chlamydia trachomatis*, the bacterial cause of trachoma, in children because there was no rapid re-emergence of infection in either study arm (38). A cohort analysis of communities in the trial's intervention arm did find for each 10% increase in the proportion of households with evidence of use at 12 months there was a 2.0% decrease (95%CI 0.2--3.9%) in community prevalence of ocular *C. trachomatis* infection over the subsequent year, but no association was found between community latrine usage and change in prevalence of active trachoma (39). The study's authors ascribed this lack of association to the long presentation of active trachoma, particularly in hyperendemic areas like Amhara, which may require longer than 1 year to resolve, even if transmission has been reduced (117). Latrine ages might not be constant across Amhara, but we controlled secular trends by including a fixed effect for survey year. The moderate association of higher sanitation usage with lower active trachoma prevalence odds may have been observable because latrines were in place longer, allowing the impact of a cleaner living environment upon active trachoma to occur.

The relative importance of WASH components, like household sanitation versus community sanitation, alongside water and hygiene, for control of NTDs remains to be established (10, 30). We did not identify any pattern of difference in the association of community sanitation usage with active trachoma by household water access and latrine usage, despite statistically significant interaction. We concluded this result was driven by the large sample size.

Few studies have examined the relationship between community sanitation usage and health outcomes (30, 80, 84, 118). Yet this information is critical for water, sanitation, and hygiene and NTD control programs. These findings may not be applicable to other diseases, so this should be an area of future research. The conclusions from this study are strengthened by its size and population-based estimates. The modified segment design provided a unique opportunity to estimate the association of community sanitation usage, deriving a contextual measure from households forming an actual aggregation, with individual disease. Surveys were cross-sectional, however, preventing causal conclusions.

Residual confounding is another possible limitation. Surveys collected limited information on hygiene practices, so these factors could not be controlled. Also, our indicator of latrine use did not measure usage by all household members or disposal of child feces. Therefore, it is an assumption that the proportion of households with a latrine in use, our measure of community sanitation usage, reflects the actual proportion of the community population that consistently deposits feces in a latrine (110). Even with this limited measure, we detected a protective association of community sanitation usage with lower prevalence odds of active trachoma, within the context of 5 years of SAFE implementation.

Though district results may vary, estimated overall prevalence of active trachoma among children aged 1 to 9 years in Amhara indicates need for continued SAFE implementation. Despite improvements over recent years (119), household latrine usage remains below 50%, and SAFE implementation should target communities with lower sanitation usage. The association of community sanitation usage with trachoma highlights need for interventions to increase community-wide sanitation demand, like community-led total sanitation, that aim to create an open defecation free environment (86). Modeling community sanitation usage and *C. trachomatis* infection would further clarify sanitation’s role in preventing transmission. Trachoma control efforts should renew emphasis on environmental improvements. Future research should focus on both increasing adoption, to reach protective community sanitation usage, and improved construction and maintenance, to ensure that usage improvements are sustained.

Acknowledgments

We would like to thank the Amhara National Regional Health Bureau and health offices, The Carter Center support staff, field teams, and study supervisors. We are especially grateful to the residents of selected communities, who gave freely of their time to participate. We acknowledge Stephanie Ogden and Dr. Matthew Freeman for early discussions on study concepts. We particularly thank Dr. Rob O'Reilly and the Emory Center for Digital Scholarship for help with data management and Dr. David Kleinbaum for assistance during analysis.

Funding

This work was supported by the Lions-Carter Center Sight-First Initiative; Emory University Laney Graduate School; and ARCS Foundation Atlanta. This study was made possible thanks to the generous support of the American People through the United States Agency for International Development (USAID) and the ENVISION project led by RTI International in partnership with The Carter Center. The contents of this article are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government.

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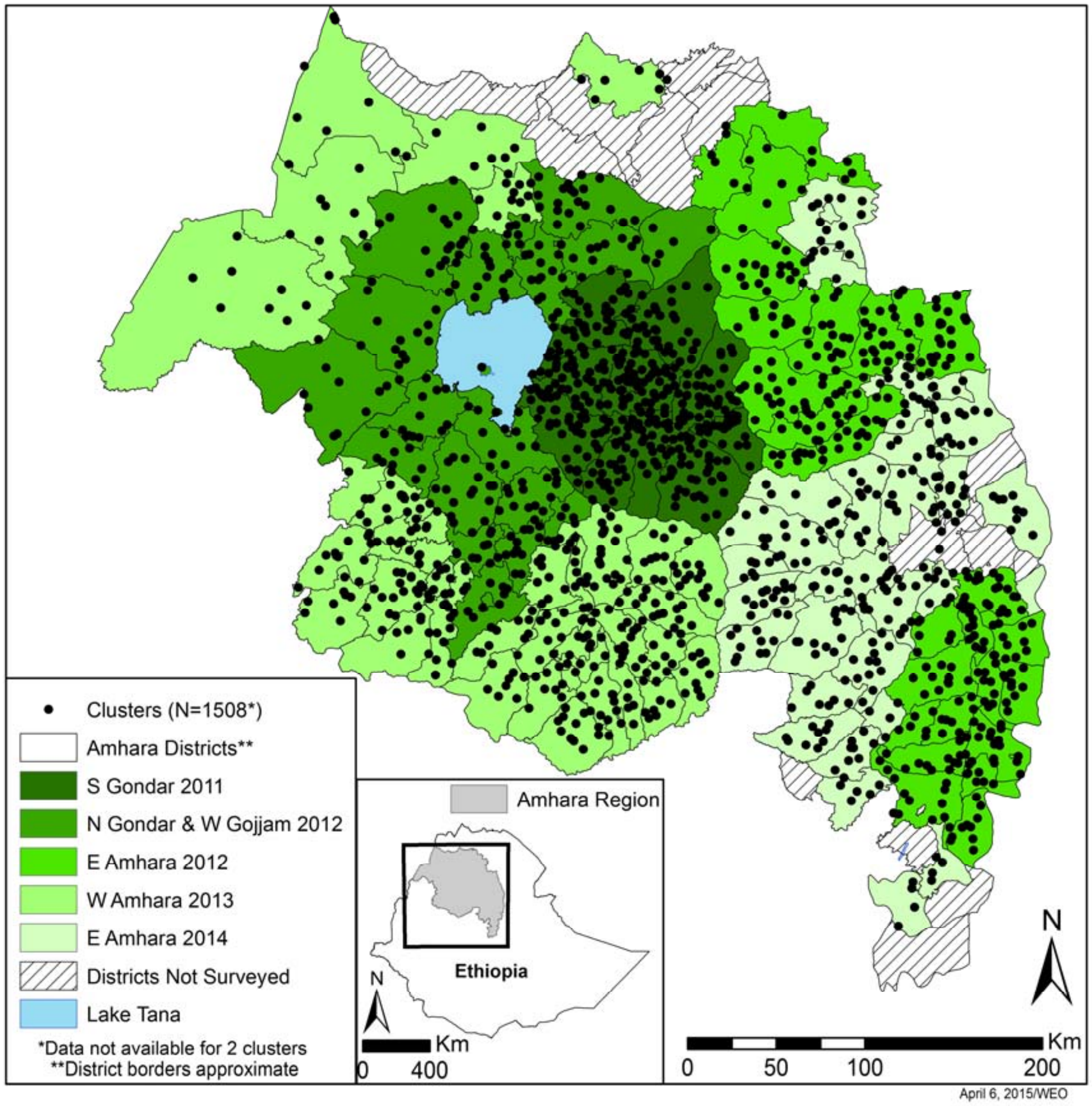

Figure 5.1 Location of clusters and districts, by survey and year, Amhara Region, Ethiopia, 2011-2014.

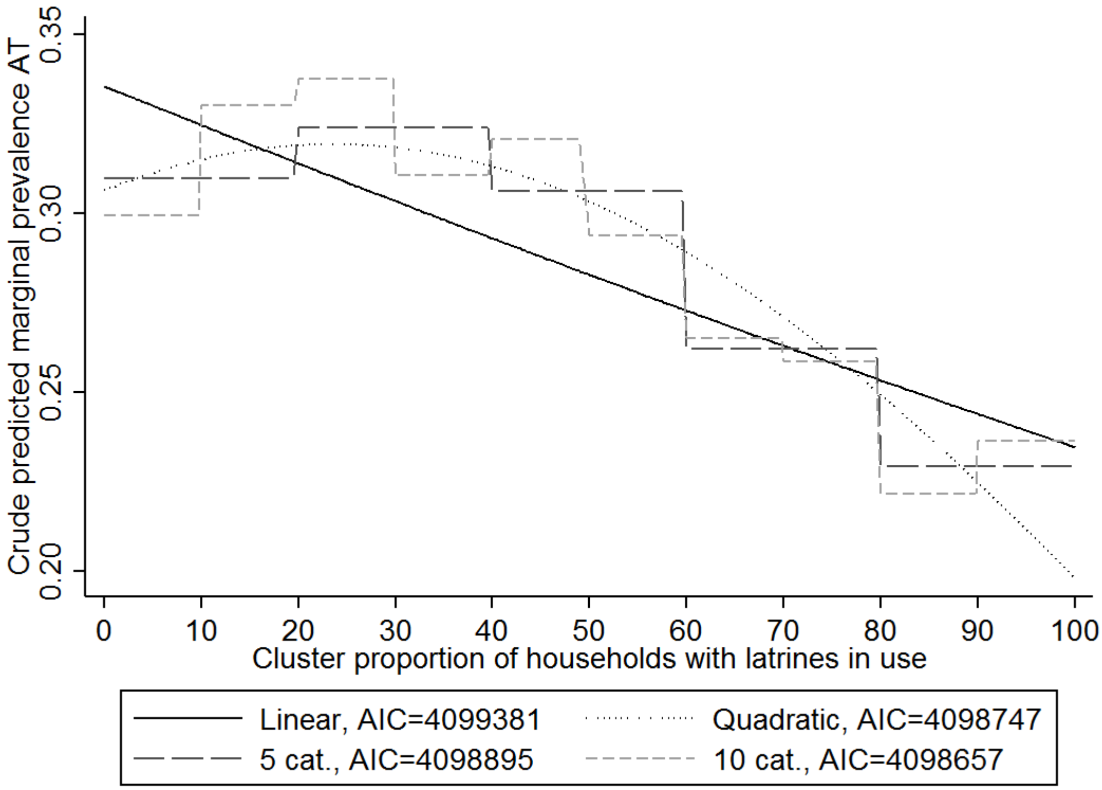

Figure 5.2 Crude predicted marginal prevalence of Active Trachoma (TF/TI) by cluster proportion of households with latrines in use in Amhara Region, Ethiopia, 2011-2014.

Table 5.1 Individual, household, and community characteristics of children aged 1 to 9 years by community proportion of households with latrines in use in Amhara Region, Ethiopia, 2011-2014.

% households with latrines in use:		0 -- <20%		20 -- <40%		40 -- <60%		60 -- <80%		80 -- 100%		Total		
	n	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	p
Active Trachoma (TF/TI)	62 869	0.31	(0.29, 0.33)	0.33	(0.30, 0.36)	0.30	(0.28, 0.33)	0.26	(0.23, 0.28)	0.23	(0.21, 0.25)	0.29	(0.28, 0.30)	<0.0001
Inflammation-Follicular (TF)	62 869	0.28	(0.26, 0.31)	0.30	(0.27, 0.34)	0.28	(0.25, 0.31)	0.23	(0.21, 0.25)	0.21	(0.19, 0.23)	0.26	(0.25, 0.27)	<0.0001
Inflammation-Intense (TI)	62 869	0.06	(0.05, 0.07)	0.06	(0.05, 0.07)	0.07	(0.05, 0.08)	0.05	(0.04, 0.06)	0.04	(0.04, 0.05)	0.06	(0.05, 0.06)	0.0259
Children, n:		**19 484**		**11 755**		**10 162**		**11 832**		**9636**		**62 869**		
Age, years	62 869	4.99	(4.94, 5.04)	5.10	(5.04, 5.17)	5.15	(5.09, 5.22)	5.18	(5.12, 5.25)	5.23	(5.15, 5.30)	5.12	(5.09, 5.14)	<0.0001
Male sex	62 806	0.48	(0.47, 0.49)	0.48	(0.47, 0.49)	0.49	(0.47, 0.50)	0.49	(0.48, 0.50)	0.48	(0.47, 0.49)	0.48	(0.48, 0.49)	0.7845
No ocular or nasal discharge	58 450	0.72	(0.69, 0.75)	0.75	(0.72, 0.78)	0.79	(0.76, 0.82)	0.77	(0.74, 0.80)	0.82	(0.80, 0.85)	0.77	(0.75, 0.78)	<0.0001
Attends school	61 185	0.17	(0.16, 0.19)	0.21	(0.20, 0.23)	0.24	(0.22, 0.26)	0.25	(0.24, 0.27)	0.29	(0.28, 0.31)	0.23	(0.22, 0.23)	<0.0001
Ever received MDA	62 767	0.74	(0.72, 0.77)	0.79	(0.76, 0.81)	0.82	(0.79, 0.84)	0.82	(0.79, 0.85)	0.85	(0.83, 0.88)	0.80	(0.78, 0.81)	<0.0001
Times received MDA:	62 158													<0.0001
0		0.26	(0.23, 0.29)	0.22	(0.19, 0.24)	0.19	(0.16, 0.21)	0.18	(0.15, 0.21)	0.15	(0.13, 0.17)	0.21	(0.19, 0.22)	
1		0.15	(0.14, 0.16)	0.15	(0.14, 0.17)	0.15	(0.14, 0.16)	0.16	(0.14, 0.17)	0.14	(0.13, 0.15)	0.15	(0.14, 0.16)	
2		0.32	(0.30, 0.34)	0.33	(0.31, 0.35)	0.31	(0.29, 0.34)	0.32	(0.30, 0.34)	0.29	(0.27, 0.32)	0.32	(0.31, 0.33)	
3		0.22	(0.20, 0.24)	0.24	(0.22, 0.27)	0.26	(0.24, 0.29)	0.26	(0.24, 0.29)	0.30	(0.27, 0.32)	0.25	(0.24, 0.26)	
4		0.04	(0.03, 0.05)	0.05	(0.04, 0.07)	0.07	(0.06, 0.09)	0.07	(0.05, 0.08)	0.10	(0.08, 0.12)	0.06	(0.06, 0.07)	
5		0.01	(0.01, 0.02)	0.01	(0.00, 0.01)	0.01	(0.01, 0.02)	0.02	(0.01, 0.03)	0.03	(0.02, 0.04)	0.01	(0.01, 0.02)	
Households, n:		**10 279**		**6764**		**6070**		**7043**		**5821**		**35 977**		
Own latrine	35 863	0.12	(0.11, 0.14)	0.38	(0.36, 0.39)	0.58	(0.56, 0.59)	0.77	(0.76, 0.78)	0.93	(0.92, 0.94)	0.52	(0.50, 0.53)	<0.0001
Own latrine in use	35 762	0.08	(0.07, 0.09)	0.32	(0.31, 0.33)	0.53	(0.52, 0.54)	0.74	(0.73, 0.75)	0.92	(0.91, 0.93)	0.48	(0.47, 0.50)	<0.0001
Water access <30 min	37 502	0.61	(0.57, 0.66)	0.69	(0.64, 0.73)	0.68	(0.62, 0.73)	0.70	(0.65, 0.74)	0.74	(0.69, 0.78)	0.68	(0.66, 0.70)	0.0035
Own:														
Radio	35 599	0.11	(0.10, 0.13)	0.13	(0.11, 0.15)	0.18	(0.16, 0.20)	0.22	(0.19, 0.24)	0.24	(0.21, 0.27)	0.17	(0.16, 0.18)	<0.0001
TV	35 589	0.00	(0.00, 0.01)	0.01	(0.01, 0.02)	0.02	(0.01, 0.03)	0.05	(0.03, 0.08)	0.12	(0.09, 0.14)	0.04	(0.03, 0.04)	<0.0001
Electricity	35 584	0.02	(0.01, 0.04)	0.06	(0.03, 0.09)	0.80	(0.05, 0.12)	0.18	(0.14, 0.23)	0.26	(0.21, 0.31)	0.11	(0.10, 0.13)	<0.0001
Mobile phone	35 584	0.11	(0.09, 0.13)	0.18	(0.15, 0.21)	0.23	(0.20, 0.26)	0.25	(0.21, 0.28)	0.32	(0.29, 0.36)	0.21	(0.19, 0.22)	<0.0001
Iron roof	35 782	0.51	(0.48, 0.55)	0.58	(0.53, 0.62)	0.67	(0.62, 0.71)	0.73	(0.70, 0.77)	0.75	(0.71, 0.79)	0.64	(0.62, 0.65)	<0.0001
Any trachoma prevention knowledge	35 565	0.52	(0.48, 0.55)	0.58	(0.53, 0.62)	0.60	(0.55, 0.64)	0.70	(0.66, 0.72)	0.70	(0.66, 0.73)	0.61	(0.60, 0.62)	<0.0001
Highest education of an adult:	35 595													<0.0001
None		0.56	(0.54, 0.59)	0.53	(0.49, 0.56)	0.49	(0.45, 0.52)	0.43	(0.40, 0.46)	0.43	(0.39, 0.47)	0.49	(0.48, 0.51)	
Religious		0.02	(0.02, 0.03)	0.03	(0.02, 0.04)	0.03	(0.02, 0.03)	0.03	(0.02, 0.04)	0.02	(0.02, 0.03)	0.03	(0.02, 0.03)	
Primary school (grade 1-6)		0.21	(0.19, 0.23)	0.16	(0.14, 0.18)	0.19	(0.16, 0.21)	0.18	(0.16, 0.20)	0.18	(0.16, 0.21)	0.18	(0.18, 0.19)	
Junior secondary (grade 5-8)		0.13	(0.11, 0.14)	0.17	(0.15, 0.19)	0.17	(0.15, 0.19)	0.19	(0.17, 0.20)	0.17	(0.15, 0.19)	0.16	(0.16, 0.17)	
Senior secondary (grade 9-12)		0.04	(0.03, 0.04)	0.06	(0.05, 0.08)	0.08	(0.07, 0.09)	0.11	(0.10, 0.12)	0.12	(0.10, 0.14)	0.08	(0.07, 0.08)	
College/University		0.00	(0.00, 0.01)	0.01	(0.01, 0.01)	0.01	(0.01, 0.02)	0.03	(0.02, 0.04)	0.04	(0.03, 0.05)	0.02	(0.02, 0.02)	
Non-formal education		0.04	(0.03, 0.05)	0.04	(0.03, 0.05)	0.04	(0.03, 0.05)	0.04	(0.03, 0.05)	0.03	(0.02, 0.04)	0.04	(0.03, 0.04)	
Communities, n:		**412**		**279**		**260**		**302**		**257**		**1510**		
Mean household wealth	1510	0.74	(0.68, 0.79)	0.95	(0.87, 1.03)	1.19	(1.09, 1.28)	1.38	(1.27, 1.49)	1.72	(1.58, 1.87)	1.17	(1.13, 1.21)	<0.0001
Density, per sq. km	1508	303	(206, 399)	391	(280, 501)	665	(348, 982)	1022	(701, 1343)	1696	(1244, 2149)	786	(670, 901)	<0.0001
Has a health facility	1414	0.15	(0.11, 0.20)	0.28	(0.22, 0.35)	0.28	(0.22, 0.35)	0.26	(0.21, 0.32)	0.33	(0.27, 0.39)	0.25	(0.23, 0.28)	0.0001
Median times received MDA	1510	2.37	(2.28, 2.47)	2.62	(2.53, 2.71)	2.72	(2.62, 2.83)	2.72	(2.63, 2.81)	2.91	(2.80, 3.02)	2.65	(2.61, 2.69)	<0.0001

*p-values from Wald adjusted F-test for categorical variables or ANOVA F-test for difference in continuous means.

Table 5.2 Association of Active Trachoma (TF/TI) with community proportion of households with latrines in use among children aged 1 to 9 years in Amhara Region, Ethiopia, 2011-2014.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Level 1 - Individuals	62 869	62 806	62 037	61 351	61 351	61 351
Level 2 - Households	35 977	35 963	35 477	35 061	35 061	35 061
Level 3 - Clusters	1510	1510	1510	1510	1510	1510
Households with latrines in use	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
≥80%	0.51 (0.35, 0.73)	0.50 (0.33, 0.75)	0.54 (0.36, 0.81)	0.62 (0.42, 0.92)	0.74 (0.49, 1.11)	0.68 (0.45, 1.04)
60-<80%	0.67 (0.47, 0.97)	0.68 (0.45, 1.03)	0.73 (0.49, 1.10)	0.78 (0.52, 1.17)	0.88 (0.58, 1.32)	0.84 (0.55, 1.26)
40-<60%	0.91 (0.66, 1.26)	0.95 (0.66, 1.35)	1.00 (0.70, 1.42)	1.02 (0.72, 1.46)	1.11 (0.78, 1.58)	1.06 (0.74, 1.52)
20-<40%	1.03 (0.76, 1.39)	1.07 (0.77, 1.49)	1.10 (0.79, 1.53)	1.11 (0.80, 1.54)	1.16 (0.83, 1.60)	1.12 (0.81, 1.55)
<20%	Ref	Ref	Ref	Ref	Ref	Ref
Adjusted for:	survey	age; sex; survey	age; sex; household latrine in use; household water access <30 min; survey	age; sex; household latrine in use; household water access <30 min; own radio, tv, mobile phone; household has electricity, iron roof; household education; survey	age; sex; household latrine in use; household water access <30 min; own radio, tv, mobile phone; household has electricity, iron roof; household education; community mean household wealth; survey	age; sex; household latrine in use; household water access <30 min; own radio, tv, mobile phone; household has electricity, iron roof; household education; community mean household wealth; community median times received MDA; survey
Random Effects						
Variance between households (SE)	0.68 (0.08)	1.05 (0.10)	1.04 (0.10)	1.03 (0.10)	1.03 (0.10)	1.03 (0.10)
Variance between clusters (SE)	2.03 (0.18)	2.52 (0.23)	2.50 (0.22)	2.41 (0.22)	2.39 (0.22)	2.38 (0.22)
ICC(household,cluster)	0.45	0.52	0.52	0.51	0.51	0.51
ICC(cluster)	0.34	0.37	0.37	0.36	0.36	0.35
MOR(household,cluster)	2.19	2.66	2.65	2.63	2.63	2.63
MOR(cluster)	4.80	6.07	6.02	5.86	5.83	5.82

*Results weighted to account for unequal probabilities of selection and down-weight non-eligible survey participants (age <1 or >9 years)

Table 5.3 Association of Active Trachoma (TF/TI) with community sanitation usage by household latrine use and water access among children aged 1 to 9 years in Amhara Region, Ethiopia, 2011-2014.

	Households own latrine in use						Households do not own latrine in use								
	Water access <30 min			Water access ≥30 min			Water access <30 min			Water access ≥30 min					
% Latrines in use per cluster	**n**	**OR**	**(95% CI)**	**n**	**OR**	**(95% CI)**	**n**	**OR**	**(95% CI)**	**n**	**OR**	**(95% CI)**	**n**	**sOR***	**(95% CI)**
≥80%	6383	0.62	(0.39, 0.99)	2332	0.51	(0.32, 0.83)	518	0.68	(0.41, 1.13)	182	0.93	(0.52, 1.67)	9415	0.67	(0.48, 0.95)
60-<80%	5870	0.83	(0.54, 1.29)	2690	0.54	(0.32, 0.90)	2006	0.87	(0.55, 1.37)	982	0.68	(0.42, 1.09)	11 548	0.76	(0.57, 1.03)
40-<60%	3636	0.87	(0.56, 1.36)	1741	0.76	(0.46, 1.24)	3094	1.10	(0.75, 1.62)	1471	1.35	(0.92, 1.96)	9942	1.01	(0.74, 1.37)
20-<40%	2587	1.14	(0.75, 1.72)	1237	0.72	(0.46, 1.13)	5282	1.07	(0.74, 1.56)	2392	1.22	(0.87, 1.69)	11 498	1.06	(0.78, 1.44)
<20%	1090	Ref		492	Ref		10 679	Ref		6687	Ref		18 948	Ref	

*Summarized odds ratio weighted by total population within strata of household water and sanitation access, adjusted for age, sex, household education, household wealth items, community mean sum of household items, community median times received MDA, and survey

Chapter 6 - Association of Community Sanitation Usage with Soil-Transmitted Helminth Infections among School-aged Children in Amhara Region, Ethiopia[2]

Abstract

This study aimed to estimate the association between community sanitation usage and soil-transmitted helminth (STH) infection among children aged 6-15 years in Amhara Region, Ethiopia. Data on STH prevalence and household latrine usage were obtained during SAFE impact surveys between 2011 and 2014. Multilevel regression was used to estimate the association between the proportion of households in the community with latrines in use and presence of STH infection, indicated by >0 eggs in stool samples. Prevalence of STH infection was estimated as 22% (95%CI 20--24%), 4% (95%CI 4--5%), and 14% (95%CI 13--16%) for hookworm (HW), *Trichuris trichiura* (TT), and *Ascaris lumbricoides* (AL), respectively. Adjusting for individual, household, and community characteristics, HW prevalence was not associated with community sanitation usage. TT prevalences were higher comparing communities with sanitation usage ≥60% and <20%. Association of community sanitation usage with AL prevalence depended on household sanitation. Community sanitation usage was not associated with AL prevalence among households with latrines in use. AL prevalence was higher comparing communities with sanitation usage ≥60% and <20%, among households without latrines in use. The relationship between STH infection and community sanitation usage remains unclear, and further research is warranted.

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[2] This chapter is a manuscript prepared for submission to a peer-reviewed journal. As such the structure, format and length are in keeping with journal requirements. Use of the plural pronoun ‘we’ refers to members of the dissertation committee and other co-authors on this submission.

Introduction

Globally, it was estimated that in 2010 approximately 1.5 billion people were infected with at least one species of soil-transmitted helminth (STH) (120). The four most common nematode worms that infect humans include: the roundworm, *Ascaris lumbricoides*; the whipworm, *Trichuris trichiura*; and, the hookworms, *Ancylostoma duodenale* and *Necator americanus* (41, 43). These intestinal parasites infect humans through exposure to eggs or larvae that develop in the environment after being deposited in feces (45). Eggs and larvae thrive in warm, moist soils of the tropics and subtropics, particularly in poorer areas with inadequate access to water and sanitation (43, 45). Of approximately 800 million people in countries of sub-Saharan Africa, it was recently estimated that 130 million, 50 million, and 37 million people were infected with hookworm, *A. lumbricoides*, and *T. trichiura*, respectively (121).

As with other neglected tropical diseases (NTDs), STH infections infrequently lead to mortality, but chronic infection results in several detrimental outcomes, including impaired physical and cognitive development, school absenteeism and poor performance, reduced work productivity among adults, adverse pregnancy outcomes, anemia, and possibly increased susceptibility to malaria, tuberculosis, and HIV (41, 43). The extent of morbidity is related to the burden of infection, the number of worms residing within the host, and the health of the host (43, 44).

Current strategies for control of STH in low-income countries focus on morbidity control through large-scale provision of anthelmintic drugs to prevent the consequences of chronic infection (40, 41). The WHO recommends periodic administration of albendazole and mebendazole to at-risk populations, including preschool-age children; school-age children; women of reproductive age, including pregnant women and lactating mothers; and other adult groups with high exposure (40). It is recognized that long-term effectiveness of de-worming efforts through mass treatment will be jeopardized without concurrent improvements to sanitation and excreta disposal behaviors (2, 43, 46-49).

With the current study, we aimed to estimate the association of the proportion of households in a community with latrines in use with prevalence of STH infections among children, aged 6 to 15 years, in Amhara, Ethiopia. We hypothesized that higher community sanitation usage will be associated with lower prevalence of these STH infections.

Materials and Methods

Study overview and subjects

Integrated surveys were conducted by the Amhara Regional Health Bureau and The Carter Center's Trachoma Control Program to provide population-based *woreda* (Ethiopian administrative units equivalent to districts) estimates of both trachoma and STH prevalence; quantify uptake of trachoma control activities (SAFE: Surgery; Antibiotics; Face washing; Environmental improvements); estimate proportions of households with water and sanitation access; and determine control strategies for each of these diseases. *Woreda* became eligible for surveying, in order of SAFE implementation, where at least five rounds of annual azithromycin mass drug administration (MDA) for trachoma had occurred.

For the current study, data were combined from four surveys conducted in distinct areas of Amhara between 2011 and 2014. The first survey was conducted in South Gondar zone between June and August 2011. The methods and results of this study have been described previously (105, 106). The next three surveys were conducted in eastern Amhara from December 2012 to January 2013, in western Amhara from June to July 2013, and in eastern Amhara from January to February 2014.

All surveys used a multi-stage cluster random sampling methodology and were powered to estimate zonal prevalences of STH infections, including *A. lumbricoides* (AL), *T. trichiura* (TT), and hookworm (HW). The smallest administrative units with population data available are *gott* (villages) and were primary sampling units. Within each eligible *woreda*, *gott* were listed according to geographical distribution and systematically selected probability proportional to population size. Within *gott*, smaller administrative units of approximately 40 households, called development teams (DT), were used as segments for a modified segment survey design (107, 108). Development teams were listed upon arrival in the community with an appropriate *gott* representative, who then drew numbers from a hat to select DTs to be surveyed. In *gott* of 40 households or less, the entire *gott* was surveyed. For the current study, selected DTs were considered clusters, the immediate geographic area of residence of participants.

In selected clusters, *gott* leaders were interviewed for community information. Heads of all households were interviewed for demographic, socioeconomic information, and knowledge and practices regarding trachoma, water, sanitation, and hygiene. Visual inspections were made of household latrines and handwashing stations. Within each cluster, one child aged 6 to 15 years old (2 to 15 years in 2011 survey) was randomly selected in each household, after enumerating all residents, and asked to provide a single stool sample. Interviews and observations were conducted with selected children about school attendance, use of latrines for defecation, receipt of anthelmintic treatment, recent infection with worms, and shoe wearing. Responses were recorded electronically using tablet computers operating on the Android platform (Google Inc.; Mountain View, CA, USA), and questionnaires at the community, household, and individual levels, along with laboratory results, were linked (109).

Measures

The exposure, community sanitation usage, was calculated as the proportion of households within the cluster with a latrine in which feces were observed in the pit and to which there was a defined path (110).

Stool sampling methods, training, and quality control have been described previously (105). Briefly, an ether-concentration method was used to enumerate the number of eggs per 1 gram of stool, fixed in 10 mL of sodium acetate-acetic acid-formalin (SAF) solution, counting from 1 to 99 eggs and then recording ≥100 if higher (122, 123). The outcomes for the current study were dichotomous indicators for presence of >0 eggs of each species (AL, HW, TT) in stool samples. Frequencies of infection intensity categories are provided in supplementary information (Table 6.4).

Covariates

Individual measures included child's age in years (centered at 10), sex, and reported school attendance. Between 2011 and subsequent surveys, some questions were asked differently, so to avoid missing values the following approaches were used to combine responses. In 2011, reported wearing of shoes was recorded as: 1) always; 2) sometimes; or 3) never. Subsequent surveys recorded whether the child was observed to be currently wearing shoes. For an indicator of shoe wearing, responses from 2011 of always wearing shoes were combined with positive observations of shoe wearing. In 2011, the child and parent/guardian were asked whether the child had received and taken albendazole or mebendazole: 1) in the past month; 2) between 1 month and 1 year; or 3) 1 year ago. The first two responses for either medication were combined to indicate receipt of medication within the last year. For a measure of recent anthelmintic treatment, responses to the 2011 question were combined with responses to the question from subsequent surveys of whether the child had taken medicine for worms in the last year. In 2011, reported use of a latrine by the child was recorded as: 1) always; 2) sometimes; or 3) never. In subsequent surveys, children were asked if they last defecated in a school latrine, family latrine, open field, or backyard. For an indicator of latrine usage, responses from 2011 of always using a latrine were combined with responses in subsequent surveys of last defecating in a school or the family's latrine. Children were also asked if they had worms in the last year.

Household access to water was dichotomized <30 min or not, based on asking how long it took to fetch water for bathing. Reported type of drinking water source was dichotomized as improved or not according to WHO/UNICEF Joint Monitoring Programme classification (124). Indicators were created for presence of a pit latrine and presence of a pit latrine in use (defined above). Household wealth was indicated by ownership of radio, television, mobile phone, metal roof, and access to electricity. A categorical variable was created for the highest level of education completed by respondents in 2011 or any household member in subsequent surveys.

Cluster wealth was calculated as the mean total per household of reported wealth indicators. Mean elevation in meters was calculated for each cluster from household measurements and evaluated as a continuous measure. Population density (km^{-2}) in 2011 was generated using the Oak Ridge National Laboratory's LandScan as an unprojected map in WGS84 with $83.33 x 10^{-4}$ degree resolution (111). Annual average volumetric soil moisture (m^3/m^3) measures for 2010, produced by the European Space Agency Climate Change Initiative (ESA CCI), were obtained as a grid file in WGS84 with a Lambert Azimuthal Equal Area projection and 0.25 degree resolution (125). Population density and soil moisture values were extracted for each cluster using geographic coordinates in ArcMap 10.1 (ESRI, Redlands, CA, USA). Population density was evaluated as a continuous measure, natural log transformed, and dichotomized at 250 people km^{-2}. Soil moisture was evaluated as a continuous measure. Soil moisture measures for 18 clusters were unavailable because of their proximity to Lake Tana. Each cluster was assigned the nearest neighbor's value. Presence of a health post, health center, or hospital was dichotomized as presence of any health facility.

Analyses

Means and frequencies were estimated with confidence intervals across categories of community sanitation usage, accounting for study design and sampling weights, based on inverse total selection probability for clusters (*gott* and DT) and individuals. Multilevel Poisson regression with robust variance was used to estimate the association between proportion of households in each cluster with a latrine in use and infection with each of three species of soil-transmitted helminths among children aged 6 to 15 years (126, 127). Potential confounders, among measures recorded in all surveys, were identified based on literature review. Reported measures for child's school attendance, location of last defecation, and having worms in past year were not modeled. An evaluation of directed acyclic graphs (DAGs) identified the same minimal sufficient set of covariates to estimate associations of community sanitation usage with each STH infection (112, 113). A sequential modeling approach, removing covariates at each level from fully-adjusted models, was also used to identify confounders based on changes in exposure estimates. Results are presented from crude, DAG-based, and fully-adjusted models for comparison.

Generalized linear mixed models were fit, specifying a random intercept for cluster and incorporating sampling weights. Robust standard errors were requested to account for clustering within *woreda*, and adaptive quadrature with 8 integration points was used. Results are reported for individual weights scaled to sum to the cluster sample size, though weights were also scaled to effective cluster sample size for comparison (114). Operationalization of exposure as a categorical measure, versus linear or quadratic, was based on a preliminary assessment considering fit and interpretability. Participants sampled in 2011 aged <6 years or missing covariates in any survey were excluded from models. Effect modification on the multiplicative scale of the association of community sanitation usage with STH infection by household latrine use, anthelmintic treatment, and by wearing of shoes (for HW infection) was evaluated with Wald tests. Measures of association were presented for community sanitation usage within strata of each potential effect modifier, as stratified prevalence ratios with a single reference category, and for household sanitation within strata of community sanitation (128). Individual and cluster mean shoe wearing were assessed as negative control exposures to detect uncontrolled confounding of the association of community sanitation usage with AL and TT infection (129). All described analyses were conducted using Stata 13.1 (StataCorp LP, College Station, TX, USA).

Study protocols were approved by Emory University Institutional Review Board (079-2006) and Amhara Regional Health Bureau. This secondary analysis was exempt from additional review.

Results

Of approximately 14,417 children selected, stool sample results were obtained for 12,754 children (88%), and the combined dataset linked community, household, and individual information and complete parasitological results for 12,208 children aged 2-15 y (85%) in 576 clusters in 133 *woreda* (Figure 6.1). Of these, 11,009 (90%) were aged 6 to 15 years, and the analysis included 9818 (89%) observations with complete results for AL and TT and 9812 (89%) observations for HW.

Table 6.1 describes individual, household, and community characteristics of children aged 6 to 15 years, overall and by community sanitation usage category.

Children in communities with lower sanitation usage had indicators of less education and access to health facilities, worse access to water for bathing and drinking, and more impoverished and less densely-populated living conditions, compared to children in communities with higher sanitation usage. Among school-aged children, 65% (95%CI 61--69%) and 85% (95%CI 82--87%) reported attending school in communities with lowest and highest sanitation usage, respectively. Of children's households, 38% (95%CI 30--46%) and 63% (95%CI 54--72%) reported an improved source of drinking water, comparing communities with lowest and highest sanitation usage respectively. Households in communities with lowest sanitation usage had a mean of 0.68 items (95%CI 0.59--0.76) compared to 1.67 items (95%CI 1.47--1.87) in communities with highest sanitation usage.

Children's shoe wearing and receipt of anthelmintics were not associated with community sanitation usage ($p=0.18$ and $p=0.19$, respectively). Communities with lower sanitation usage were in less densely populated areas with lower elevation compared to communities with higher sanitation usage ($p<0.01$ and $p<0.01$, respectively). Soil moisture was significantly lower in communities with lower sanitation usage compared to communities with higher sanitation usage (p<0.01), but the magnitude of difference may not reflect meaningful change.

In 576 clusters, mean community sanitation usage was 50% (95%CI 47--52%) and ranged from 0% in 44 clusters (8%) to 100% in 14 clusters (2%). HW was the most prevalent of these STH across surveyed areas of Amhara, infecting almost a quarter of school-aged children (Table 6.1, 22%, 95%CI 20--24%). TT was least prevalent, infecting 4% of school-aged children (Table 6.1, 95%CI 4--5%).

Table 6.2 presents results from crude and adjusted models of the association of community sanitation usage with prevalence of each STH, controlling for selected covariates and survey. Results were generally robust to sampling weight scaling method, but potentially meaningful identified differences between weighted and unweighted results are discussed.

Hookworm infection

Community sanitation usage ≥20% was associated with lower HW prevalence, compared to usage of <20%, adjusting only for survey. The difference was statistically significant, however, only where usage was between 60--<80% (Crude: 20--<40% PR 0.69, 95%CI 0.46--1.03; 40--<60%, PR 0.77, 95%CI 0.51--1.16; 60--<80%, PR 0.67, 95%CI 0.46--0.98; ≥80%, PR 0.80, 95%CI 0.54--1.18). Adjusting for cluster altitude, population density, mean wealth indicators, and soil moisture attenuated the association towards or past the null across usage categories (DAG-based: 20--<40% PR 0.88, 95%CI 0.59--1.32; 40--<60%, PR 1.01, 95%CI 0.69--1.52; 60--<80%, PR 1.05, 95%CI 0.70--1.56; ≥80%, PR

1.21, 95%CI 0.82--1.80). Further adjusting for age, sex, shoe wearing, anthelmintic treatment, household latrine use, access to bathing water and improved drinking water source, wealth and education did not meaningfully change estimates. In this latter model, adjusting for community sanitation usage and other factors, household ownership of a latrine in use was also not associated with hookworm prevalence (PR 1.00, 95%CI 0.91--1.08).

Trichuris trichiura infection

TT prevalence in communities with sanitation usage ≥40% was more than double the prevalence in communities with sanitation usage of <20%. Community sanitation usage was significantly associated with elevated prevalence of TT at usage ≥60%, compared to usage <20% (Crude: 20--<40% PR 0.91, 95%CI 0.39--2.12; 40--<60%, PR 2.08, 95%CI 0.96--4.53; 60--<80%, PR 2.82, 95%CI 1.23--6.48; ≥80%, PR 4.12, 95%CI 1.80--9.42). Estimates from DAG-based and full model were not meaningfully different. After adjusting for all potential confounders, community sanitation usage ≥60% was significantly associated with higher prevalence of TT, compared to usage <20 (Full: 20--<40% PR 0.89, 95%CI 0.39--2.05; 40--<60%, PR 2.10, 95%CI 0.95--4.63; 60--<80%, PR 2.50, 95%CI 1.02--6.14; ≥80%, PR 3.70, 95%CI 1.40--9.76). Adjusting for community sanitation usage and other factors, household ownership of a latrine in use was associated, but not significantly, with TT prevalence (PR 0.93, 95%CI 0.78--1.11). When included in full models as negative control exposures, individual shoe wearing was associated with TT infection, but association was not statistically significant (Full: PR 0.79, 95%CI 0.61--

1.03). Cluster mean shoe wearing was not associated with TT infection (Full: PR 1.04, 95%CI 0.93--1.16).

Ascaris lumbricoides infection

Community sanitation usage of ≥20% was associated with higher prevalences of AL compared to usage of <20% (Crude: 20--<40% PR 1.62, 95%CI 1.02--2.58; 40--<60%, PR 1.47, 95%CI 0.98--2.21; 60--<80%, PR 2.02, 95%CI 1.28--3.19; ≥80%, PR 2.48, 95%CI 1.58--3.90). Estimates from DAG-based and full model were not meaningfully different. Adjusting for all potential confounders moderately attenuated estimated associations (Full: 20--<40% PR 1.47, 95%CI 0.99--2.18; 40--<60%, PR 1.44, 95%CI 0.95--2.16; 60--<80%, PR 1.80, 95%CI 1.09--2.98; ≥80%, PR 2.35, 95%CI 1.37--4.01). Adjusting for community sanitation usage and other factors, household ownership of a latrine in use was not associated with AL prevalence (PR 1.01, 95%CI 0.89--1.14). Variables for shoe wearing, individually and aggregated to cluster, were not associated with AL infection when included in full models as negative control exposures (Full, individual: PR 0.96, 95%CI 0.84--1.09; Cluster mean reported/observed, PR 0.96, 95%CI 0.91--1.02).

Effect modification

Table 6.3 shows prevalence ratios comparing children in respective strata of community and household sanitation usage. No significant modification of the association of community sanitation usage with HW prevalence was detected, either by household latrine usage (p=0.15) and wearing shoes (p=0.13, data not shown) individually, or combined (p=0.22, data not shown), or by reported receipt of anthelmintic treatment in past year (p=0.29, data not shown). No significant modification of the association of community sanitation usage with TT prevalence was detected, either by household latrine usage (p=0.40) or reported receipt of anthelmintic treatment in past year (p=0.86, data not shown).

Significant modification was detected of the association of community sanitation usage with AL prevalence by household latrine usage, adjusting for all covariates (p<0.01). The first two groups of columns compare prevalences of AL between communities with sanitation usage ≥20% to those with usage <20%, among children from households with and without latrines in use. Community sanitation usage was not associated with AL prevalence among children from households with latrines in use (20--<40% PR 1.13, 95%CI 0.65--1.96; 40--<60%, PR 1.12, 95%CI 0.67--1.87; 60--<80%, PR 1.31, 95%CI 0.74--2.34; ≥80%, PR 1.68, 95%CI 0.93--3.06). Children from households without latrines in use had increasingly higher prevalences of AL comparing communities with higher sanitation usage and usage <20% (20--<40% PR 1.50, 95%CI 1.00--2.25; 40--<60%, PR 1.41, 95%CI 0.90--2.19; 60--<80%, PR 2.03, 95%CI 1.24--3.33; ≥80%, PR 3.92, 95%CI 2.11--7.27). Examining the joint association of increased community sanitation and a household latrine in use, children in households with a latrine in use in communities with any level of sanitation usage had higher prevalences of AL compared to children in households without latrines in use in communities with sanitation usage <20%.

The last column in table 6.3 compares prevalences between children from households with and without latrines in use by community sanitation usage. Within communities with sanitation usage ≥80%, children in households with a latrine in use had significantly lower prevalence of AL compared to children in households without a latrine in use (≥80%, PR 0.60, 95%CI 0.44--0.81); while in communities with sanitation usage <20%, children in households with a latrine in use had significantly higher prevalence of AL compared to children in households without a latrine in use (<20%, PR 1.40, 95%CI 1.00--1.96).

Household latrine characteristics

The mean age of all latrines observed in communities was 2.96 years (95%CI 2.76--3.15). Handwashing containers, not including presence of soap and water, were available at 13% (95%CI 11--16%) of all children's household pit latrines. The availability of a handwashing container significantly increased from 3% (95%CI 2--6%) to 23% (95%CI 18--30%) between communities with lowest and highest sanitation usage, respectively ($p<0.01$). The availability of a handwashing container was not associated with infections of AL ($p=0.78$), TT ($p=0.53$), or HW ($p=0.76$), among children in households with a latrine.

Discussion

Our findings show no evidence that increased community sanitation usage was protective against the three most-common STH infections among children aged 6 to 15 years in Amhara Region, Ethiopia. No significant association was detected between increased community sanitation usage and decreased prevalence of HW infection after adjusting for potential confounders. Significantly higher prevalences of TT infection were observed in communities with higher sanitation usage, controlling for individual, household, and community characteristics. The association of community sanitation usage with AL infection depended on household sanitation usage, and children from households with latrines in use had a lower or higher prevalence depending on community sanitation usage.

These findings contrast with current understanding of the relationship between sanitation and STH infection, and the relationship between community sanitation and these STH remains unclear. Much of the evidence of the relationship between sanitation and STH has focused on the association of household sanitation access or usage with STH infection, rather than community sanitation. Two recent meta-analyses examined accumulated evidence of the relationship between sanitation and STH infection and found protective associations of household sanitation access with lower odds of any STH, AL, TT, and HW infection (50, 130). In their systematic review, Ziegelbauer *et al.* identified only six studies that examined community sanitation and STH infection (50). Two recent studies from Tanzania found that higher community sanitation coverage was associated with lower prevalence odds of AL and weakly associated with higher prevalence odds of HW, controlling for individual, household, and environmental measures (97, 98). In the following discussion, we provide possible explanations for our findings and suggest areas for further study.

We observed no association of community or household sanitation with HW prevalence, after controlling for individual, household and community characteristics. Infection intensity directly represents transmission rate because no STH reproduction occurs within the host (41). As an indicator of transmission, frequencies of HW infection intensities did not significantly differ across categories of community sanitation usage (Table 6.4). Hookworm may live up to 7 years in the gut (41). In the absence of deworming, which was infrequent in this population, it is perhaps not unusual that a reduction in prevalence was not observed for HW within the latrines' times in place (131).

There was little relative difference in AL prevalence by community sanitation usage among children in households with latrines in use. It is understood that most AL transmission clusters within households and families (78, 132). A study from Bangladesh found that household-related exposures explained 58% of clustering of AL worm burden at the household level, indicating the importance of the domestic domain in transmission (132). Therefore, not finding a significant association between community sanitation usage and AL prevalence in this population subset is less surprising (44). Among children from households without latrines in use, AL prevalence increased with greater community sanitation usage relative to communities with lowest sanitation usage. This subset of children resided in households last to adopt household sanitation in their communities, which in itself might indicate an increased likelihood of worse conditions or practices related to other AL transmission routes.

A significant protective association of sanitation with AL prevalence was observed among children from households with latrines in use compared to children from households without latrines in use among communities with sanitation usage ≥80%. This result corresponds with odds ratios of 0.62 (95%CI 0.44--0.88) and 0.78 (95%CI 0.60--1.00), representing reductions in the odds of AL infection with household sanitation use, observed in recent meta-analyses (50, 130). This finding could indicate that household latrines may only be protective against AL at specific levels of community sanitation usage. A study in Tanzania found a non-significant protective association of household latrine ownership when community latrine coverage was included in the model, but each 10% increase in latrine coverage was associated with a reduction in AL prevalence odds (98). Community sanitation usage is not frequently reported in studies of household sanitation, so further studies are warranted to confirm this finding.

Among communities with low sanitation usage, children in households with a latrine in use had significantly higher AL prevalence compared to children in households without a latrine in use. The strength and significance of this association was not robust to the exclusion of sampling weights (data available upon request), so this result should be interpreted with caution. A plausible explanation for the finding may be that in communities with fewer latrines overall, there is increased reliance on sharing sanitation infrastructure between families. A recent systematic review found a consistent pattern of elevated risk of helminth infection among those relying on shared sanitation facilities (133). Curtale *et al.* and Tshikuka *et al.* found that increased numbers of users and sharing increased intensity of AL infections (52, 53). Shared sanitation is not currently included in the definition of improved sanitation because facilities may not be accessible at all times and poor cleanliness may not fully separate users from contact with human waste (133). Information on latrine cleanliness and maintenance was not collected, so further exploration of the mechanism behind this possible transmission was not possible. Future studies should collect information on latrine sharing, particularly in contexts with limited sanitation availability, and indicators of latrine construction, maintenance, and cleanliness to explore these possible transmission pathways.

Our dataset allowed for characterization of each child's immediate and community environment. As an evaluation activity, however, limited information could be collected during household surveys. Our indicator of household latrine usage balanced standard recommendations with the logistical realities of program evaluation, but the aggregated measure for community sanitation usage may not sufficiently reflect levels of fecal contamination in the environment. For example, there was no actual measure of consistent latrine usage by all household members or measures of child feces disposal and hand hygiene. The difficulty with accurately measuring sanitation usage has been acknowledged (134). Furthermore, as a cross-sectional study, the possibility that latrine promotion activities were targeted to areas with higher STH prevalences cannot be ruled out.

Some unmeasured factors were controlled through application of remote-sensing information, but residual confounding is possible with any observational study. TT prevalence and infection intensity were observed to increase with increasing community sanitation usage (Tables 6.2 and 6.4), but household ownership of a latrine in use was associated with lower prevalence of TT, adjusting for other factors, though not significantly. Overall prevalences of AL were higher in communities with highest sanitation usage. Community sanitation usage may reflect unmeasured factors related to urbanization that were not completely controlled by included measures. Urban areas are generally believed to have higher prevalences of AL and TT compared to rural areas (135).

In their review, Brooker *et al.* found no consistent pattern of differences between urban and rural communities for the prevalence of AL and TT among a limited number of studies, but concluded that hookworm appeared equally prevalent in rural and urban settings (45).

Our statistical models adjusted for population density using a remote-sensing derived measure. This measure of population density, along with our other included measures, may not have adequately controlled for confounding related to urbanization. To identify residual confounding, individual and cluster mean shoe wearing were included in DAG-based and fully-adjusted models for AL and TT infection as negative control exposures (129). If these control exposures do not cause AL and TT infection and have a comparable set of confounders as community sanitation usage, then any detected association of these exposures with the outcomes would indicate bias in the main association of interest (129). Under the necessary assumptions of comparability between these measures of shoe wearing and community sanitation, our results did not strongly indicate the presence of any residual confounding with AL, though more so for TT based on the indicator for individual shoe wearing.

In the current study, we found no evidence of a protective association of community sanitation usage against STH infection and only weak evidence of a protective association with household sanitation, except for AL under conditions of high community sanitation usage. Sanitation may convey other private and public benefits, including convenience, dignity, privacy, and safety (62). The extent of sanitation usage in this study reflects promising uptake of sanitation, but reductions in STH prevalence may still be pending additional improvement in sanitation-related behaviors.

Acknowledgments

We would like to thank the Amhara National Regional Health Bureau and health offices and The Carter Center support staff, field teams, and study supervisors. We particularly thank Dr. Rob O’Reilly and the Emory Center for Digital Scholarship for help with data management. We thank Dr. Simon Brooker and Dr. Matthew Freeman for their helpful suggestions. Finally, we are especially grateful to the residents of selected communities, who gave freely of their time to participate.

Financial Support and Disclaimers

This work was supported by the Lions-Carter Center Sight-First Initiative; Emory University Laney Graduate School; and ARCS Foundation Atlanta. This study was made possible thanks to the generous support of the American People through the United States Agency for International Development (USAID) and the ENVISION project led by RTI International in partnership with The Carter Center. The contents of this article are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government.

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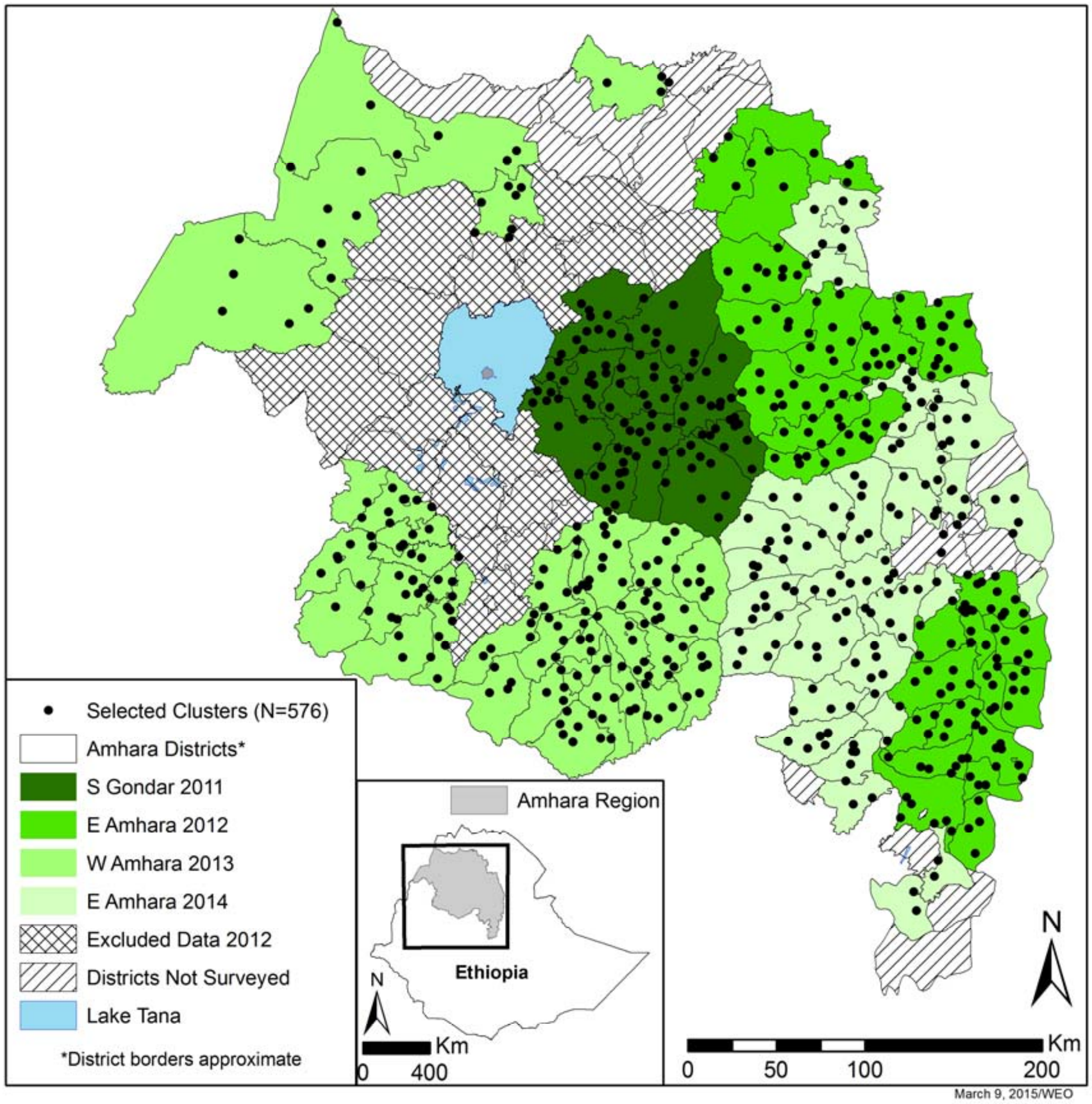

Figure 6.1 Location of clusters and districts, by survey and year, Amhara Region, Ethiopia, 2011-2014.

Table 6.1 Individual, household, and community characteristics of 11,009 children aged 6 to 15 years by community proportion of households with latrines in use in Amhara Region, Ethiopia, 2011-2014.

% households with latrines in use:		0 -- <20%		20 -- <40%		40 -- <60%		60 -- <80%		80 -- 100%		Total		
Children, aged 6-15 years, n:		2472		1837		2202		2467		2031		11009		
Communities, n:		137		97		109		125		108		576		
	n	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	Mean/%	(95% CI)	p
A. lumbricoides	11009	0.10	(0.07, 0.13)	0.16	(0.12, 0.21)	0.14	(0.11, 0.18)	0.16	(0.12, 0.20)	0.17	(0.13, 0.20)	0.14	(0.13, 0.16)	0.04
T. trichiura	11009	0.03	(0.02, 0.04)	0.03	(0.01, 0.06)	0.04	(0.03, 0.06)	0.06	(0.04, 0.09)	0.07	(0.05, 0.10)	0.04	(0.04, 0.05)	0.01
Hookworm	11009	0.24	(0.20, 0.29)	0.18	(0.13, 0.24)	0.20	(0.16, 0.26)	0.23	(0.18, 0.28)	0.24	(0.19, 0.30)	0.22	(0.20, 0.24)	0.47
Age, years	10961	9.68	(9.53, 9.82)	10.02	(9.86, 10.17)	10.08	(9.93, 10.23)	10.12	(9.98, 10.26)	10.28	(10.10, 10.46)	10.02	(9.96, 10.09)	<0.01
Male sex	11000	0.48	(0.46, 0.51)	0.49	(0.46, 0.52)	0.50	(0.47, 0.52)	0.48	(0.46, 0.51)	0.45	(0.42, 0.47)	0.48	(0.47, 0.49)	0.09
Reported attending school	10833	0.65	(0.61, 0.69)	0.72	(0.66, 0.76)	0.80	(0.76, 0.83)	0.79	(0.76, 0.82)	0.85	(0.82, 0.87)	0.76	(0.74, 0.78)	<0.01
eported Always Wearing Shoes (2011)	1029	0.06	(0.01, 0.19)	0.02	(0.00, 0.08)	0.10	(0.02, 0.39)	0.04	(0.01, 0.14)	0.30	(0.14, 0.53)	0.09	(0.05, 0.17)	<0.01
Any Observed Shoes (No 2011)	9795	0.46	(0.40, 0.52)	0.57	(0.49, 0.66)	0.51	(0.43, 0.59)	0.43	(0.36, 0.50)	0.48	(0.40, 0.55)	0.48	(0.46, 0.51)	0.13
Any Reported or Observed Shoes (All)	10824	0.42	(0.37, 0.47)	0.52	(0.44, 0.60)	0.49	(0.42, 0.57)	0.41	(0.35, 0.48)	0.47	(0.40, 0.54)	0.46	(0.44, 0.48)	0.18
Anthelmintics in past year (2011)	1016	0.09	(0.05, 0.18)	0.06	(0.02, 0.15)	0.16	(0.05, 0.43)	0.12	(0.06, 0.23)	0.27	(0.14, 0.44)	0.13	(0.09, 0.18)	0.06
Anthelmintics in past year (No 2011)	9224	0.17	(0.12, 0.22)	0.17	(0.12, 0.23)	0.14	(0.11, 0.18)	0.21	(0.16, 0.26)	0.20	(0.15, 0.26)	0.18	(0.16, 0.20)	0.28
Anthelmintics in past year (All)	10240	0.16	(0.12, 0.21)	0.16	(0.11, 0.21)	0.14	(0.11, 0.18)	0.20	(0.16, 0.26)	0.21	(0.16, 0.27)	0.17	(0.15, 0.20)	0.19
Reported always use latrine (2011)	1026	0.05	(0.02, 0.12)	0.18	(0.11, 0.28)	0.41	(0.23, 0.61)	0.58	(0.42, 0.73)	0.92	(0.81, 0.97)	0.36	(0.27, 0.46)	<0.01
Reported last use of latrine (No 2011)	9643	0.10	(0.08, 0.13)	0.37	(0.32, 0.42)	0.56	(0.52, 0.60)	0.77	(0.73, 0.80)	0.88	(0.84, 0.91)	0.54	(0.51, 0.57)	<0.01
Reported use of latrine (All)	10669	0.10	(0.08, 0.12)	0.35	(0.30, 0.40)	0.55	(0.51, 0.59)	0.76	(0.72, 0.79)	0.88	(0.85, 0.91)	0.53	(0.50, 0.55)	<0.01
Worms in past year	10251	0.34	(0.29, 0.39)	0.35	(0.29, 0.42)	0.33	(0.27, 0.39)	0.36	(0.32, 0.41)	0.37	(0.31, 0.43)	0.35	(0.32, 0.37)	0.85
Household owns latrine	10986	0.13	(0.11, 0.16)	0.43	(0.39, 0.46)	0.63	(0.60, 0.65)	0.81	(0.79, 0.82)	0.95	(0.94, 0.96)	0.59	(0.56, 0.61)	<0.01
Household owns latrine in use	10963	0.09	(0.07, 0.11)	0.37	(0.35, 0.39)	0.57	(0.55, 0.59)	0.77	(0.75, 0.78)	0.93	(0.92, 0.95)	0.54	(0.52, 0.57)	<0.01
Bathing water access <30 min	10769	0.49	(0.41, 0.56)	0.57	(0.48, 0.65)	0.62	(0.53, 0.70)	0.71	(0.64, 0.78)	0.68	(0.59, 0.75)	0.61	(0.58, 0.65)	<0.01
Improved drinking water source	10792	0.38	(0.30, 0.46)	0.53	(0.42, 0.63)	0.56	(0.46, 0.64)	0.55	(0.46, 0.63)	0.63	(0.54, 0.72)	0.52	(0.48, 0.56)	<0.01
Household owns:														
Radio	10770	0.12	(0.09, 0.14)	0.14	(0.10, 0.20)	0.21	(0.17, 0.25)	0.23	(0.19, 0.26)	0.25	(0.21, 0.31)	0.19	(0.17, 0.21)	<0.01
TV	10772	0.00	(0.00, 0.02)	0.02	(0.01, 0.04)	0.02	(0.01, 0.04)	0.05	(0.03, 0.08)	0.09	(0.06, 0.14)	0.04	(0.03, 0.05)	<0.01
Electricity	10766	0.01	(0.00, 0.03)	0.07	(0.03, 0.15)	0.08	(0.04, 0.14)	0.19	(0.13, 0.27)	0.22	(0.15, 0.30)	0.11	(0.09, 0.14)	<0.01
Mobile phone	10766	0.16	(0.13, 0.21)	0.24	(0.19, 0.30)	0.30	(0.26, 0.35)	0.28	(0.23, 0.34)	0.32	(0.27, 0.38)	0.26	(0.24, 0.28)	<0.01
Iron roof	10783	0.45	(0.40, 0.51)	0.57	(0.49, 0.65)	0.68	(0.62, 0.74)	0.76	(0.70, 0.80)	0.75	(0.69, 0.81)	0.64	(0.62, 0.67)	<0.01
Highest education of an adult:	10774													<0.01
None		0.53	(0.47, 0.58)	0.49	(0.42, 0.56)	0.42	(0.37, 0.49)	0.39	(0.34, 0.43)	0.36	(0.30, 0.43)	0.44	(0.41, 0.46)	
Religious		0.03	(0.02, 0.05)	0.02	(0.01, 0.03)	0.03	(0.02, 0.05)	0.05	(0.03, 0.07)	0.03	(0.02, 0.05)	0.03	(0.03, 0.04)	
Primary school (grade 1-6)		0.20	(0.17, 0.25)	0.14	(0.11, 0.18)	0.19	(0.15, 0.23)	0.19	(0.15, 0.23)	0.22	(0.17, 0.27)	0.19	(0.17, 0.21)	
Junior secondary (grade 5-8)		0.15	(0.12, 0.17)	0.21	(0.17, 0.25)	0.21	(0.18, 0.24)	0.19	(0.17, 0.22)	0.21	(0.18, 0.26)	0.19	(0.18, 0.20)	
Senior secondary (grade 9-12)		0.03	(0.02, 0.04)	0.07	(0.05, 0.09)	0.10	(0.08, 0.12)	0.12	(0.10, 0.14)	0.12	(0.09, 0.15)	0.09	(0.08, 0.10)	
College/University		0.00	(0.00, 0.01)	0.01	(0.01, 0.03)	0.01	(0.01, 0.02)	0.02	(0.02, 0.04)	0.03	(0.02, 0.04)	0.02	(0.01, 0.02)	
Non-formal education		0.05	(0.04, 0.08)	0.06	(0.04, 0.09)	0.04	(0.03, 0.05)	0.05	(0.03, 0.07)	0.03	(0.02, 0.05)	0.05	(0.04, 0.05)	
Mean household wealth	576	0.68	(0.59, 0.76)	0.92	(0.78, 1.07)	1.23	(1.08, 1.37)	1.45	(1.28, 1.61)	1.67	(1.47, 1.87)	1.19	(1.12, 1.26)	<0.01
Landscan density, per km^2	574	451	(206, 695)	414	(198, 629)	405	(237, 573)	1013	(544, 1481)	1459	(896, 2023)	764	(596, 933)	<0.01
Has a health facility	553	0.08	(0.04, 0.14)	0.19	(0.12, 0.29)	0.23	(0.16, 0.33)	0.18	(0.12, 0.26)	0.30	(0.21, 0.40)	0.19	(0.16, 0.23)	<0.01
Elevation, m	575	2043	(1962, 2124)	2259	(2140, 2379)	2263	(2178, 2348)	2359	(2250, 2468)	2317	(2220, 2415)	2244	(2215, 2273)	<0.01
Soil moisture, m^3/m^3	575	0.25	(0.24, 0.26)	0.26	(0.25, 0.27)	0.26	(0.25, 0.28)	0.29	(0.28, 0.29)	0.29	(0.28, 0.30)	0.27	(0.27, 0.27)	<0.01

*p-values from Wald adjusted F-test for categorical variables or ANOVA F-test for difference in continuous means.

Table 6.2 Association of infection with hookworm, *Trichuris trichiura*, and *Ascaris lumbricoides* with community proportion of households with latrines in use and household ownership of latrine in use among children aged 6 to 15 years in Amhara Region, Ethiopia, 2011-2014.

			Crude		DAG-based		Full	
Infection	**Sanitation Measure**		**PR**	**(95% CI)**	**PR**	**(95% CI)**	**PR**	**(95% CI)**
Hookworm	**Community:**	**≥80%**	0.80	(0.54, 1.18)	1.21	(0.82, 1.80)	1.19	(0.81, 1.77)
	% Households with	**60-<80%**	0.67	(0.46, 0.98)	1.05	(0.70, 1.56)	1.03	(0.70, 1.52)
	latrines in use per	**40-<60%**	0.77	(0.51, 1.16)	1.01	(0.69, 1.50)	0.99	(0.68, 1.44)
	cluster	**20-<40%**	0.69	(0.46, 1.03)	0.88	(0.59, 1.32)	0.87	(0.59, 1.29)
		<20%	Ref		Ref		Ref	
	Household:							
	Latrine in use		--	--	--	--	1.00	(0.91, 1.08)
	No latrine in use		--	--	--	--	Ref	
Trichuris trichiura	**Community:**	**≥80%**	4.12	(1.80, 9.42)	3.56	(1.39, 9.14)	3.70	(1.40, 9.76)
	% Households with	**60-<80%**	2.82	(1.23, 6.48)	2.50	(1.01, 6.21)	2.50	(1.02, 6.14)
	latrines in use per	**40-<60%**	2.08	(0.96, 4.53)	2.01	(0.90, 4.49)	2.10	(0.95, 4.63)
	cluster	**20-<40%**	0.91	(0.39, 2.12)	0.89	(0.38, 2.08)	0.89	(0.39, 2.05)
		<20%	Ref		Ref		Ref	
	Household:							
	Latrine in use		--	--	--	--	0.93	(0.78, 1.11)
	No latrine in use		--	--	--	--	Ref	
Ascaris lumbricoides	**Community:**	**≥80%**	2.48	(1.58, 3.90)	2.33	(1.42, 3.84)	2.35	(1.37, 4.01)
	% Households with	**60-<80%**	2.02	(1.28, 3.19)	1.81	(1.12, 2.92)	1.80	(1.09, 2.98)
	latrines in use per	**40-<60%**	1.47	(0.98, 2.21)	1.45	(0.98, 2.16)	1.44	(0.95, 2.16)
	cluster	**20-<40%**	1.62	(1.02, 2.58)	1.49	(1.01, 2.20)	1.47	(0.99, 2.18)
		<20%	Ref		Ref		Ref	
	Household:							
	Latrine in use		--	--	--	--	1.01	(0.89, 1.14)
	No latrine in use		--	--	--	--	Ref	

Results weighted to account for unequal probabilities of selection
AL, TT: N, Children (clusters): 9818 (574)
HW: N, Children (clusters): 9812 (574)
Crude: Survey
DAG-based: Altitude; Population density; Community mean sum HH wealth indicators; Soil moisture; Survey
Full, HW: Age; Sex; Shoes; Anthelmintic treatment; Bathing water source <30min; Improved drinking water source; Household owns: radio, tv, electricity, mobile phone, iron roof; Household education; Altitude; Soil Moisture; Community mean sum HH wealth indicators; Population density; Survey
Full, AL & TT: Age; Sex; Anthelmintic treatment; Bathing water source <30min; Improved drinking water source; Household owns: radio, tv, electricity, mobile phone, iron roof; Household education; Altitude; Soil Moisture; Community mean sum HH wealth indicators; Population density; Survey

Table 6.3 Association of hookworm, *Trichuris trichiura*, and *Ascaris lumbricoides* with community sanitation usage by household latrine use among children aged 6 to 15 years in Amhara Region, Ethiopia, 2011-2014.

Infection	% Households with latrines in use per cluster	Community Sanitation by Household Sanitation: Latrine in Use			No Latrine in Use			Joint Association: Latrine in Use			
		+/-	PR	(95% CI)	+/-	PR	(95% CI)	PR	(95% CI)	PR*	(95%CI)
Hookworm	≥80%	335/1315	1.15	(0.68, 1.96)	23/93	1.22	(0.80, 1.87)	1.19	(0.81, 1.75)	0.98	(0.77, 1.24)
	60-<80%	300/1316	1.03	(0.61, 1.73)	90/448	0.91	(0.60, 1.38)	1.06	(0.72, 1.56)	1.16	(0.97, 1.40)
	40-<60%	181/956	0.91	(0.54, 1.52)	180/698	1.05	(0.73, 1.52)	0.94	(0.64, 1.38)	0.89	(0.80, 1.00)
	20-<40%	81/514	0.82	(0.48, 1.38)	149/891	0.89	(0.60, 1.32)	0.84	(0.56, 1.28)	0.95	(0.78, 1.16)
$p_{interaction}$= 0.1483	<20%	33/154	Ref		445/1610	Ref		1.03	(0.76, 1.41)	1.03	(0.76, 1.41)
Trichuris trichiura	≥80%	123/1527	3.30	0.99, 11.02)	9/107	2.60	(0.81, 8.30)	3.59	(1.42, 9.08)	1.38	(0.88, 2.17)
	60-<80%	93/1525	2.08	(0.68, 6.32)	34/504	2.90	(1.20, 7.03)	2.26	(0.90, 5.65)	0.78	(0.56, 1.08)
	40-<60%	52/1085	1.85	(0.66, 5.22)	42/836	2.09	(0.91, 4.79)	2.02	(0.90, 4.49)	0.97	(0.70, 1.33)
	20-<40%	13/583	0.78	(0.25, 2.38)	28/1012	0.90	(0.39, 2.05)	0.85	(0.33, 2.19)	0.94	(0.60, 1.46)
$p_{interaction}$= 0.3990	<20%	7/180	Ref		48/2010	Ref		1.09	(0.49, 2.40)	1.09	(0.49, 2.40)
Ascaris lumbricoides	≥80%	256/1394	1.68	(0.93, 3.06)	30/86	3.92	(2.11, 7.27)	2.36	(1.45, 3.85)	0.60	(0.44, 0.81)
	60-<80%	255/1363	1.31	(0.74, 2.34)	89/449	2.03	(1.24, 3.33)	1.84	(1.14, 2.98)	0.91	(0.76, 1.08)
	40-<60%	173/964	1.12	(0.67, 1.87)	124/754	1.41	(0.90, 2.19)	1.57	(1.05, 2.34)	1.11	(0.85, 1.47)
	20-<40%	99/497	1.13	(0.65, 1.96)	166/874	1.50	(1.00, 2.25)	1.58	(1.06, 2.35)	1.06	(0.80, 1.39)
$p_{interaction}$= 0.0040	<20%	28/159	Ref		188/1870	Ref		1.40	(1.00, 1.96)	1.40	(1.00, 1.96)

Results weighted to account for unequal probabilities of selection

Adjusted: Age; Sex; Anthelmintic treatment; Household has latrine in use; Bathing water source <30min; Improved drinking water source; Household owns: radio, tv, electricity, mobile

*PR, Prevalence ratio for household latrine in use versus household latrine not in use, within strata of community sanitation usage

$p_{interaction}$, Global Wald

Table 6.4 Intensity (eggs per gram) of infection by community proportion of households with latrines in use among children aged 6 to 15 years in Amhara Region, Ethiopia, 2011-2014.

		Community Sanitation Usage										
		<20%		20-<40%		40-<60%		60-<80%		≥80%		
Species	Eggs/gram	n	%	n	%	n	%	n	%	n	%	p
Hookworm												
	0	1919	0.76	1536	0.83	1794	0.79	1975	0.77	1597	0.76	0.47
	1-49	490	0.22	254	0.17	359	0.20	410	0.21	377	0.23	
	50-99	24	0.01	3	0.00	10	0.01	18	0.01	18	0.01	
	≥100	9	0.00	3	0.00	5	0.00	8	0.00	5	0.00	
Trichuris trichiura												
	0	2382	0.97	1753	0.97	2069	0.96	2279	0.94	1858	0.93	0.01
	1-49	55	0.02	41	0.03	93	0.04	129	0.06	133	0.07	
	50-99	1	0.00	1	0.00	3	0.00	2	0.00	3	0.00	
	≥100	4	0.00	1	0.00	3	0.00	1	0.00	3	0.00	
Ascaris lumbricoides												
	0	2205	0.91	1510	0.84	1836	0.86	2024	0.84	1660	0.83	0.13
	1-49	175	0.07	193	0.11	215	0.09	272	0.11	220	0.11	
	50-99	33	0.01	43	0.02	59	0.02	57	0.02	57	0.03	
	≥100	29	0.01	50	0.02	58	0.02	58	0.02	60	0.03	

*p-values from Wald adjusted F-test for categorical variables.

Chapter 7 - Prediction of Low Community Latrine Coverage using Environmental and Social Factors in Amhara Region, Ethiopia[3]

Abstract

Background: Despite improvements over the past decade, sanitation coverage remains low in areas of Amhara Region, Ethiopia. This study aimed to develop and validate a diagnostic tool for predicting the probability that communities have low sanitation coverage, based on environmental and social conditions.

Methods: Community coverage with household pit latrines was measured between 2011 and 2014. Information on environmental and social conditions for community location were obtained from available data sources and linked with community data using a geographic information system. Logistic regression was used to identify factors predictive of low community sanitation coverage (<20% vs. ≥20%). Model selection minimized Akaike Information Criteria. Training and testing datasets were used to geographically and temporally validate the selected prediction model. Model calibration and discrimination were also assessed. A map of model-predicted probabilities of low community sanitation coverage was created using estimated regression coefficients.

Results: Among 1,502 communities, 344 (22.90%) had sanitation coverage below 20%. The selected model included measures for high topsoil gravel content, topographic moisture potential, population density, altitude, rainfall, and had reasonable predictive discrimination (AUC 0.75, 95%CI 0.72, 0.78). High gravel content in topsoil and

[3] This chapter is a manuscript prepared for submission to a peer-reviewed journal. As such the structure, format and length are in keeping with journal requirements. Use of the plural pronoun ‘we’ refers to members of the dissertation committee and other co-authors on this submission.

topographic moisture potential were strongly associated with low community sanitation coverage, after controlling for community wealth and other factors.

Conclusions: A model using environmental and social factors from available data sources predicted low community sanitation coverage for areas across Amhara Region with fair discrimination. This method could assist local sanitation programs to target vulnerable areas with additional activities or alternate sanitation technologies.

Keywords: sanitation; geographic information systems; remote sensing; prediction modeling; Ethiopia

Introduction

Globally, it is estimated that in 2011, 15% of the world's population or just over 1 billion people lacked access to any sanitation facility and defecated in the open (1). The majority of these people live in rural areas, where 90% of all open defecation takes place (1). This crisis remains despite progress made in the past two decades; rates of open defecation have declined from 25% in 1990, and in 2011, 64% of the world population had access to improved sanitation facilities (1). Similarly, despite drastic increases in the past decade, recent estimates of ownership of a household latrine in rural areas of Ethiopia range between approximately 40-70% with actual usage of the latrines lower still (105, 136, 137), indicating that a large proportion of the population lacks access to a sanitation facility and practices open defecation.

Community-led total sanitation (CLTS) is a mobilization approach aimed at ending open defecation through community-wide action. It was initially developed and employed in

Bangladesh (86), but it is now being widely implemented throughout the world. In Ethiopia, a variant of CLTS, incorporating additional behavior change approaches and a focus on hygiene behaviors, has been adopted within the National Hygiene and Sanitation Strategy (NHSS)(93). CLTS promotes households constructing their own basic pit latrines, using locally available materials, with the aim of providing a means to end open defecation.

Pit latrines, or privies, represent the most basic form of “hygienic” sanitation to prevent immediate or subsequent human contact with excreta (http://www.wssinfo.org). Specifications for the construction of an adequate latrine have long been established (61). CLTS imposes a minimal focus on the design of the latrines, focusing first on ending open defecation through the deposition of feces in a fixed location and subsequently on improving the quality of the facilities (86). As a result, the quality of built latrines is dependent upon many factors, including the resources, skill, time, willingness, and capability of household residents tasked with building their own latrine. An evaluation of latrine promotion in Ethiopia identified several construction deficiencies with built pit latrines that could influence their acceptability and sustainability (137). Recent work has also drawn attention to the influence of factors beyond the individual or household on behaviors related to water, sanitation, and hygiene, including the impact of contextual factors, such as time of year, land ownership, geographical conditions, and climate, that may motivate or deter positive sanitation behaviors like latrine construction and maintenance (138, 139).

Environmental conditions may have a profound effect on household uptake or maintenance of sanitation in response to a community-based sanitation intervention, like community-led total sanitation. Soil conditions were reported by household respondents as a barrier to latrine construction in Ghana, Tanzania, and Kenya (90-92). Greater extent of vegetation or land cover near a community may increase available materials, facilitating construction (62). Alternatively, local changes related to economic development, like deforestation, increased population density, and proximity to roads reportedly motivated increased adoption in Benin and Kenya (91, 96). Just as local geographic conditions may deter or incite initial adoption of household sanitation, environmental factors may strongly influence the durability of built latrines, particularly the rudimentary ones constructed in response to CLTS activities (Figure 7.1). Destruction of latrines through flooding during the rainy season were reported in Kenya and The Gambia and could decrease sanitation coverage (91, 94).

The relationship between environmental and social conditions in a location and variations in pit latrine coverage has not been widely examined (140). The current study aimed to develop and validate a diagnostic tool for estimating the probability of a community having low sanitation coverage based on its environmental and social conditions. This tool could then be used to identify and target vulnerable areas with additional promotional activities or alternate sanitation technologies more suitable for local conditions.

Methods

Study area and population

Amhara Region is located in northwest Ethiopia and has a total area of approximately 150,000 km^2. Geographically, the region is centered on Lake Tana and encompasses a range of physical landscapes, characterized by rugged mountains, plateaus, valleys, and gorges (141). Elevation ranges from 519 m in the northwestern areas to 4,420 m among mountains in the northeast. Land cover consists primarily of shrublands and croplands (142). Based on a 2007 census, Amhara Region has a population of approximately 17 million people (143).

For the current study, data were combined from five surveys conducted by the Amhara Regional Health Bureau and The Carter Center's Trachoma Control Program in distinct areas of Amhara between 2011 and 2014 to provide population-based estimates of household water and sanitation access. The first survey was conducted in South Gondar zone between June and August 2011. The methods and results of this study have been described previously (105). The second survey was conducted in North Gondar and West Gojjam zones between May and June 2012. The next three surveys were conducted in eastern Amhara from December 2012 to January 2013, in western Amhara from June to July 2013, and in eastern Amhara from January to February 2014.

All surveys used a multi-stage cluster random sampling methodology and were powered to estimate *woreda* prevalences of active trachoma. The smallest administrative unit with population data available are *gott* (villages) and were primary sampling units. Within each eligible *woreda*, *gott* were systematically selected from a geographically-ordered line listing probability proportional to population size. Within *gott*, smaller administrative units of approximately 40 households, called development teams (DT), were used as segments for a modified segment survey design (107, 108). Development teams were listed upon arrival in the community with an appropriate *gott* representative, who then drew numbers from a hat to select DTs to be surveyed. In *gott* of 40 households or less, the entire *gott* was surveyed. For the current study, selected DTs were considered clusters, the immediate geographic area of residence of participants. In each cluster, all household were surveyed.

Heads of household were interviewed for demographic, socioeconomic information, and knowledge and practices regarding water, sanitation, and hygiene. Visual inspections were made of household latrines. Responses were recorded electronically using tablet computers operating on the Android platform (Google Inc.; Mountain View, CA, USA) (109).

Geographic Information

Geographic coordinates in World Geodetic System 1984 (WGS84) were collected using tablet computers at each household (except 2013 survey, where coordinates were only collected at 2 households per community). Household coordinates were averaged to provide a single point for each community, and these were projected to Universal Transverse Mercator (UTM) zone 37N.

Outcome

Community sanitation coverage was calculated as the proportion of households within the cluster observed to have a latrine. Whether or not the latrine had been used was not considered because usage may influence latrine maintenance and *vice versa*. The aim of this study was to explore contextual determinants of latrine coverage, simplistically excluding behavioral factors. Community sanitation coverage was dichotomized, and coverage <20% was considered the outcome of interest.

Environmental and Social Predictors

Candidate environmental and social predictors were identified *a priori* based on literature review. Data sources were obtained with information for the study region on potential environmental and social predictors of latrine coverage. Table 7.1 lists each obtained variable, hypothesized influence on sanitation coverage, data source, and how the variable was created or transformed for analysis. Hypothesized influence may be positive or negative, recognizing the possibility that some variables may represent multiple influences on latrine uptake and sanitation coverage (140).

Information on soil texture class and gravel content was obtained from the Harmonized World Soil Database (HWSD, v.1.2) (144), which combines regional and national updates with information within the FAO-UNESCO Digital Soil Map of the World (145). Information for the dominant topsoil in each soil mapping unit were used. Subsoil values were not available for all locations, but, where available, soil content values were highly correlated between top- and subsoil.

Land surface form and topographic position, or moisture potential, were obtained from the United States Geological Survey Africa Ecosystems Mapping project (146). This project used SRTM elevation data to classify seven land surface form classes (plains, irregular plains, escarpments, hills, breaks/foothills, low mountains, high mountains/deep canyons) based on categorizations of local slope and relief. The obtained topographic position dataset had been created using 90m SRTM elevation data and a 3 arc-second Drainage Direction dataset, to identify two classes of topographic position (uplands and lowlands/depressions), using slope measures for raster cells and contributing areas from "upstream" raster cells, that indicated potential for water to flow to a point, without considering climate or soil attributes (147).

Elevation for the study region was obtained from NASA Shuttle Radar Topographic Mission (SRTM) digital elevation data processed by the Consortium for Spatial Information of the Consultative Group for International Agricultural Research (148). Annual Normal Density Vegetation Index (NDVI) for 2011 was obtained from the Africa Soil Information Service (149). Annual total rainfall was calculated from interpolated surfaces with mean monthly precipitation 1950-2000 (150). A shapefile representing paved, gravel, or dirt/sand roads for Amhara was obtained from the Global Roads Open Access dataset (151). Population density in 2011 per square kilometer was generated using the Oak Ridge National Laboratory's LandScan (111). All raster surfaces were clipped to Amhara's geographic extent and projected to Universal Transverse Mercator (UTM) zone 37N. Community coordinates were overlaid on raster surfaces in ArcMap 10.1, and values for predictors were extracted per community to create an analysis dataset.

A measure of community wealth was calculated as the mean of the total number of wealth indicators reported by households during interviews, including radio, television, electricity, mobile phone, and an iron roof. Two additional control variables were included for time and season of survey activities. A variable for time trend was created based on years since July 2011, the month the first survey began, using the 15th as the reference date. An indicator of whether the survey was conducted during the *kiremt* rainy season (June-September) was also generated.

Statistical Analyses

Logistic regression was used to identify social and environmental factors predictive of low community sanitation coverage (<20% versus ≥20%). To allow for temporal and geographic validation of the model, the full dataset combining information from all five surveys was partitioned into training and testing datasets (Figure 7.2). The training dataset included data from three surveys begun between 2011-2012. The testing dataset included data from two surveys conducted between 2013-2014.

Collinearity of predictors was first assessed in the full dataset based on calculated condition indices and variance decomposition proportions (152). Using the training dataset and forcing in control variables, a model selection approach was used, fitting all possible subsets of predictors to maximize model fit based on Akaike Information Criteria (AIC) (99, 153). The Akaike weight was calculated for each of the best-fitting models to describe its suitability as a probability given this candidate set of models (153). The sum of Akaike weights was also calculated for each predictor from the models in which it was included to determine its relative importance (153). Estimated coefficients from the selected model were then fit to testing data.

Because of the observed difference in frequency of low sanitation coverage between the training and testing datasets, a recalibrated model was also fit to the testing data (154). Predicted probabilities from the model initially applied to the testing data were transformed using the logit transformation. These log odds were then entered as an independent variable, specifying a coefficient of one, into a new logistic model of the testing data, which estimated a new intercept. Outcome probability was then recalculated for each community from this model.

Finally, using the complete dataset, measures of association with low sanitation coverage were estimated for selected predictors, and possible improvements in model prediction and changes in estimates from including a measure of community wealth were evaluated. Model selection and estimation of measures of association were repeated using generalized estimating equations (GEE) with an exchangeable correlation structure to account for possible correlation of outcomes within districts (152). Based on the Quasilikelihood under the Independence model Criterion (QIC) including a penalty for the number of parameters (QICu), the selected GEE model included the same predictors as the ordinary logistic model (155). Results using GEE were similar to those from the ordinary logistic model that are presented here (Table 7.5).

The Hosmer-Lemeshow statistic was calculated to assess model fit to training, testing, and complete data (152), and calibration was assessed by plotting predicted probabilities against observed probabilities by deciles of predicted probability. Discrimination of all models was assessed using receiver-operator curves and calculating the c-statistic for area under the curve (152). A nonparametric approach was used to compare ROC curves (156).

A map of model-based probability of low community sanitation coverage was calculated in ArcMap 10.1, by applying the inverse logit function to the linear sum of the intercept and regression coefficients times their local values from raster surfaces for selected environmental and social predictors. Analyses were performed with SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Communities

Across Amhara Region, 1,510 communities were surveyed in eligible districts between 2011-2014. Geographic coordinates were not available for 2 communities (<1%). Six communities' coordinates were placed outside the region or in areas without predictor information and were dropped (<1%). The complete dataset contained information on 1,502 communities (Figure 7.2). The training dataset contained information on 876 communities, and the testing dataset contained information on 626 communities.

Table 7.2 presents characteristics of communities in training, testing, and complete datasets. Of 1,502 communities, 344 (22.90%) had sanitation coverage below 20% and were located throughout the region (Figure 7.2). The distributions of most environmental and social conditions were similar between testing and training datasets. Clay loam was the most frequent soil texture (34.09%), and the distribution of clay (22.83% and 36.10%)

and sandy clay loam (26.94% and 14.06%) differed between training and testing datasets, respectively.

Of 1,502 communities, 651 (43.34%) locations were classified as low mountainous areas. Elevation, ranging from 568 m to 3644 m, and percent slope, ranging from 0.04% to 40.54%, reflected topographic variation across study areas. Of 1,502 communities, 59 (3.93%) communities were located in low-lying areas indicating high topographic moisture potential. Surveyed communities were predominantly rural with limited accessibility. Approximately half of all surveyed communities were located in areas with estimated population density of 113.53 people km^{-2} in 2011 and more than 4 km from a georeferenced paved, gravel, or dirt/sand road. Overall, communities were economically deprived as reflected by low median values of mean totals of wealth indicators reported by households.

Model development

No collinearity was detected among candidate predictors using the complete dataset. Table 7.3 shows eight models selected from all-possible subsets with an AIC within 2 units of the minimum AIC (AIC_{min}=880.29), indicating little difference in estimated likelihood between models. The variable for land surface form was not selected for any model. The small ratios of Akaike weights between model 1 and other models (1.6-2.8) indicates only weak support for this model, among these 8 models. High gravel and soil texture indicators were not selected for any of the same models, indicating worse fit if modeled together. Soil texture was strongly associated with high gravel content ($p<0.01$), and no community with topsoil classified as clay had high gravel content. The selected, best-fitting prediction model included variables for high gravel content, altitude, rainfall, population density, low-lying land, and controlled for time since July 2011 and season of survey.

Model calibration and validation

There was no indication that the selected model did not fit training data well (Figure 7.3, Hosmer-Lemeshow, p=0.63). When applied to testing data, the model fit less well and over-predicted probability of a community having low sanitation coverage (Figure 7.3, Hosmer-Lemeshow, p<0.01). Figure 7.4 shows the ROC curves for each model. With training data, the model demonstrated reasonable discriminatory ability (AUC 0.75, 95%CI 0.71, 0.79). Discrimination declined when the model was applied to testing data (AUC 0.69, 95%CI 0.63, 0.74). Model recalibration reduced over-prediction (Figure 7.3), but tests did not indicate better fit (Hosmer-Lemeshow, p<0.01) and discriminatory ability was unchanged (AUC 0.69, 95%CI 0.63, 0.74). The final model fit combined data well and maintained discriminatory ability (Hosmer-Lemeshow, p=0.91; AUC 0.75, 95%CI 0.72, 0.78).

Environmental and social conditions and low community sanitation coverage

Based on fitting the selected model to the complete dataset (Table 7.4), communities in areas with high topsoil gravel content had almost double the odds of low sanitation coverage compared to communities in areas with low gravel content (OR 1.76, 95%CI 1.28, 2.41), independent of other conditions. Communities in low-lying areas had almost three times the odds of low sanitation coverage (OR 2.74, 95%CI 1.49, 5.02) compared to areas without high moisture potential, adjusting for other conditions. Communities in areas with higher population density, higher elevation, and higher rainfall were significantly more likely to have better sanitation coverage. Communities surveyed during the rainy season, independent of other factors, had almost three times the odds of low sanitation coverage (OR 2.59, 95%CI 1.69, 3.96).

Fitting an alternate model including a variable for community wealth did not meaningfully change estimated measures of association (Table 7.4), except population density and time since 2011 were no longer significantly associated with low sanitation coverage. An increase of 1 in mean total wealth indicators was associated with a 58% decrease in the odds of low community sanitation coverage (OR 0.42, 95%CI 0.32, 0.55), controlling for other factors. Including this variable led to a small but significant increase in model discrimination (AUC 0.77, 95%CI 0.74, 0.80) ($p<0.01$).

Figure 7.5 shows geographic distribution of predicted probabilities for communities having low sanitation, based on estimated coefficients for environmental and social conditions, adjusting for survey season and year. The map highlights areas in the northwestern areas of North Gondar zone, the northern half of Wag Hemira zone, and areas on the northern and northeastern shores of Lake Tana.

Discussion

Our study used information on environmental and social conditions from a variety of existing data sources to develop a model to predict low sanitation coverage among communities of Amhara Region. Based on training data, the model predicted whether or not less than 20% of households in a community had a latrine with fair discrimination. The model's discriminatory performance suffered when applied to populations from distinct areas surveyed at later dates. We identified environmental conditions associated with the occurrence of poor sanitation coverage, before and after controlling for a measure of community wealth. Finally, the model was used to produce a map of the predicted probability that communities have poor sanitation based on their local environmental and social conditions.

Using our selected model, communities from areas where topsoil had higher gravel content were found to have significantly higher odds of poor sanitation, compared to where topsoil has low gravel content, controlling for other factors. Soil characteristics and resultant behavior represent a complex science. We based our hypotheses regarding pit collapse on the relationship of texture and gravel content with soil cohesiveness and stability. Soils with a larger proportion of sand, silt, or clay are considered coarse, medium, or fine, respectively. Cohesive soils, the most stable, commonly have finer textures: clay, silty clay, sandy clay, clay loam, and sometimes silty or sandy clay loam (157). Cohesive soils become only moderately stable with medium textures of silt or silt loam and least stable with coarse textures of sand or loamy sand and gravel content (157, 158). In study communities, soil texture was highly associated with gravel content. Areas with clay loam, loam, and sandy clay loam had higher frequencies of gravel content compared to areas with clay, which did not have any high gravel content. Our model selection chose high gravel content as the best soil-related predictor of low sanitation coverage in our data. The use of continuous measures for soil percentage content of sand, silt, and clay and gravel content would have allowed for more universal application but was avoided because of concerns about accuracy. Future studies should explore the use of these alternate measures. Future applications of this approach should also consider including the major soil group classifications (159). These classifications combine multiple aspects of soil characterization, however, and the mechanistic relationship with latrine pit collapse is less clear. One soil group in particular is known to lead to structural difficulties and contributes to soil collapse. Vertisols, constituting the "black cotton" soils common throughout South Sudan and parts of Ethiopia, have high clay content but are expansive in nature and have a high collapse risk (157). The current study might have been strengthened by exploring the inclusion of an indicator for this soil group to potentially better characterize the risk of soil collapse.

Soil conditions related to collapsibility and rock content were identified in a global review as challenges to both construction and durability of household latrines (139). The recommended depth for pit latrines is approximately 2 m, though the specific pit volume needed depends on its intended lifespan, the number of users, and anal cleansing materials used (61). In their guide to on-site sanitation, Franceys *et al.* described how cohesive soils may appear self-supporting when first excavated, but over time bonding properties of the soil may be lost, making it almost impossible to predict if or when soil may collapse (95). At approximately 3,000 lbs per cubic yard, soil's weight alone could exert extreme pressures on pit walls, which would only be exacerbated by other factors, such as natural zones of weakness, water content, weather conditions, and the depth of excavation, that influence the stability of excavation walls (157).

The stability of latrine pits influences both adoption and sustainability of latrines in sub-Saharan Africa. In Ghana, Jenkins and Scott described how soil conditions were an external barrier to sanitation adoption that operated late in the decision process, after households show preference and intention, by impeding construction (90). Similarly, in Benin and Tanzania, individuals motivated to adopt sanitation reported that unsuitable soil conditions were an obstacle (92, 160). After sanitation has been adopted, collapse of latrine pits due to weak soil structure, particularly during the rainy season, was reported as a problem hindering sanitation coverage in Kenya (91).

In addition to the influence of poor soil conditions, heavy rain and flooding can exacerbate structural weaknesses of the rudimentary on-site sanitation options found in sub-Saharan Africa (161). A follow-up study of 666 provided latrines in The Gambia documented how 77 of the latrines collapsed over the course of two wet seasons (94). The study's authors described how sandy soil became liquefied, causing the latrines' cement slabs and ring blocks to sink or collapse under their own weight. In contrast to our hypothesis, we found that areas with higher rainfall had significantly lower odds of poor sanitation, adjusting for other factors in the model. Rainfall was highest in the western areas of Amhara that also have higher levels of sanitation. As such, annual rainfall may predict sanitation coverage, but it may not reflect mechanisms leading to poor sanitation. Instead, an alternative predictor of poor sanitation for future studies may be rainfall intensity. The southeastern part of Amhara has been shown to have higher intensity rainfall, as indicated by the mean amount of rainfall on a day with rain, than western areas (141). Whether or not the surveys in our study were conducted during the main *kiremt* rainy season, from June to September, was found to be strongly associated with higher odds of poor sanitation, which could also reflect the influence of rainfall on coverage estimates. This measure was included as a control variable, but the observed association, adjusting for other factors, may be an important consideration for future efforts to estimate sanitation coverage levels using household surveys.

The indicator for low-lying areas, with high topographic moisture potential, highlighted areas on the northeastern and northern edges of Lake Tana. Of all the predictors, this measure had the strongest association with poor sanitation coverage. These areas flood regularly, and the inhabitants reportedly continue to reside in the area during these times. In Kenya, flooding was a major reported constraint to sanitation coverage in certain districts, where latrines were reported to fill up and overflow or collapse during the rainy season, after which residents prefer open defecation to the difficult and expensive repairs needed for their latrines (91).

Flooding, high rainfall, and soil type have been described previously as challenges for sanitation (90-92, 94, 160, 161). Our study quantifies the association of these factors with occurrence of poor sanitation across Amhara Region. The Ethiopian Ministry of Health acknowledged the influence of environmental factors like soil structure, topography, and climate in its NHSS (93). Therefore, what may be needed in these areas, identified to be at high risk of poor sanitation, is information on appropriate and affordable solutions to the environmental challenges they face. For example, it is recommended that all latrine pits are lined to their full depth in order to prevent collapse (95). Pit collapse can be hazardous to the person excavating, disturbing to users, and can discourage households from sustaining improved sanitation practices (93, 95, 157). Stabilized soil blocks are an environmentally sustainable and affordable alternative to fired brick that are gaining recognition in East Africa and could be used for lining pit latrines (162). Where local materials are unavailable or inappropriate, the NHSS acknowledges the need for social marketing, creation of local service providers, and creative financing options (93). So if presses for block production were available and accessible, then local artisans might be best positioned to address this problem.

Similar alternative approaches may also be needed to provide sanitation for populations living in flood-prone areas. A full review of solutions is beyond the scope of this discussion, but there are few sustainable on-site sanitation options for flood-prone areas (163). Raised pit latrines (95) have been constructed in the riverine areas of Bangladesh, where communities inhabit small islands, called "chars," left as rivers subside and that are periodically inundated when rivers rise again. An intervention program there raises houses, tube wells, and pit latrines on earthen "plinths" to protect them from floodwaters and in this way reports success extending sanitation coverage and asset protection to the residents of these communities (164). The intervention provides a subsidy for families to raise these plinths, but flexibility for such an approach is accorded within the NHSS where local ground conditions are particularly adverse (93). The model developed by our study could assist health and sanitation authorities and programs to identify areas where these alternate interventions may be needed, based on adverse environmental conditions.

Our selected model had a reasonably high ability to classify communities as having low sanitation coverage using information available on the Internet. We developed this model using a training dataset from a population-based household survey and validated it using surveyed populations distinct in time and location. Interestingly, model discrimination was only slightly improved by inclusion of a measure of community wealth. This community wealth measure was derived from information collected at great cost during extensive household surveys. Comparing model prediction utilizing only community information versus household information would be an interesting next step.

To our knowledge, a predictive model for sanitation coverage using environmental and social conditions has not been developed previously. Any model is only as good as its data, however. Care was taken to choose optimal data sources, but their accuracy at the scale utilized might be limited. For example, soil data was originally compiled from different sources with varying quality per region, though East Africa was covered by more reliable data sources (144). Regardless, the predictive model documented here can only improve in the future as more environmental information becomes available.

The map based on the predictive model highlights spatial heterogeneity in the probability of poor sanitation coverage across Amhara Region. Additional studies to examine and confirm the reasons for poor coverage in these areas are warranted. All surveyed areas had received five years of SAFE implementation, which includes sanitation promotion within the “E” component. The Federal Ministry of Health also launched the Health Extension

Program in 2003, which trains extension workers to provide disease prevention and health promotion services in rural communities (165). As such, we attribute the observed variability to the adverse environmental conditions described above. A recent study described high geographic inequality for improved sanitation within countries across sub-Saharan Africa (166). Pullan *et al.* suggested that areas with lowest access to sanitation are likely the most challenging in terms of environmental conditions (166). Our results demonstrate that environmental conditions, independent of community wealth, significantly predict poor sanitation coverage. It is hoped that the developed tool can benefit programs in Amhara and elsewhere by improving the targeting of information and resources to bring about practical and sustainable sanitation improvements to these areas most in need.

Acknowledgments

We would like to thank the Amhara National Regional Health Bureau and health offices, The Carter Center support staff, field teams, and study supervisors. We are especially grateful to the residents of selected communities, who gave freely of their time to participate. We acknowledge Dr. Gonzalo Vazquez-Prokopec, Dr. Julie Clennon, Dr. Donal Bisanzio, and Dr. Cecile Janssens for instruction and early discussions on study methods and approach.

Funding

This work was supported by the Lions-Carter Center Sight-First Initiative; Emory University Laney Graduate School; and ARCS Foundation Atlanta. This study was made possible thanks to the generous support of the American People through the United States Agency for International Development (USAID) and the ENVISION project led by RTI International in partnership with The Carter Center. The contents of this article are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government.

Figure 7.1 Examples of household pit latrines built in rural areas of Amhara Region, Ethiopia (Photo credit: William Oswald)

Table 7.1 Factors hypothesized to influence community having low sanitation coverage in Amhara Region, Ethiopia, 2011-2014.

Variable	Hypothesized influence on sanitation coverage	Reason	Data and source	Variable creation
USDA soil texture classes			Harmonized World Soil Database, v1.2 (150). Includes a 30 arc-second GIS raster image linked to an attribute database with characteristics of topsoil (0-30 cm) and subsoil (30-100 cm).	Indicators created for clay, clay loam, and loam, setting sandy clay loam as referent.
Clay	Positive	More stable soil		
Clay Loam	Positive	More stable soil		
Loam	Positive or Negative	More or less stable soil		
Sandy Clay Loam	Positive	More stable soil		
High soil gravel content	Negative	Soils with higher gravel content are less stable	Harmonized World Soil Database, v1.2 (150). Includes a 30 arc-second GIS raster image linked to an attribute database with characteristics of topsoil (0-30 cm) and subsoil (30-100 cm).	Volume percentage gravel (materials >2mm) in topsoil included values of 1 and 29, 31, and 32 within study area. To create an indicator of higher gravel content, 1 was coded as 0, and 29, 31, 32 were coded as 1.
Surface form	Positive or negative	Specific land forms may capture other mechanisms determining latrine pit collapse.	United States Geological Survey Africa Ecosystems Mapping project (152)	Indicators created for each land surface form found in the study area.
Low-lying land	Negative	Areas with higher topographic moisture potential may be more likely to flood.	United States Geological Survey Africa Ecosystems Mapping project (152)	Indicator created for low-lying land, based on two classes of topographic position (uplands and lowlands/depressions).
Altitude	Positive or negative	Altitude may capture other mechanisms determining latrine pit collapse.	NASA Shuttle Radar Topographic Mission (SRTM) digital elevation data processed by the Consortium for Spatial Information of the Consultative Group for International Agricultural Research (154)	Altitude divided by 100
Percent slope	Negative	Greater slope may increase soil collapse.	Same as altitude.	Calculated in ArcMap 10.1 (ESRI, Redlands, CA, USA)
Annual Normalized Density Vegetation Index (NDVI) 2011	Positive or negative	Higher vegetation may increase availability of materials for latrine construction or decrease demand for sanitation by providing areas for open defecation.	Africa Soil Information Service (AfSIS) MODIS Collection: Vegetation Indices, April 2014 Release, Center for International Earth Science Information Network (CIESIN), Columbia University (155)	NDVI multiplied by 10.
Total annual rainfall	Negative	Higher annual rainfall result in flooding or damage to latrines.	Interpolated surfaces with mean monthly precipitation (mm) from 1950-2000 (156) (Accessed January 20, 2015 from http://www.worldclim.org)	Surfaces were added in ArcGIS 10.1 to get total annual rainfall. Total annual rainfall (mm) divided by 100.
Population density 2011	Positive	Higher population density may increase demand for sanitation by reducing areas for open defecation and need for privacy.	Oak Ridge National Laboratory's LandScan (111)	Population density $\log_{10}$ transformed.
Distance to roads	Negative	Greater distance to roads may decrease demand for sanitation as it reflects lower perceived need. Lower access to roads reflects lower exposure to new ideas and markets and lack of mobility.	Global Roads Open Access dataset (157)	Shapefile with paved, gravel, or dirt/sand roads used to create raster surface for Amhara Region indicating distance in kilometers to a road in ArcGIS 10.1

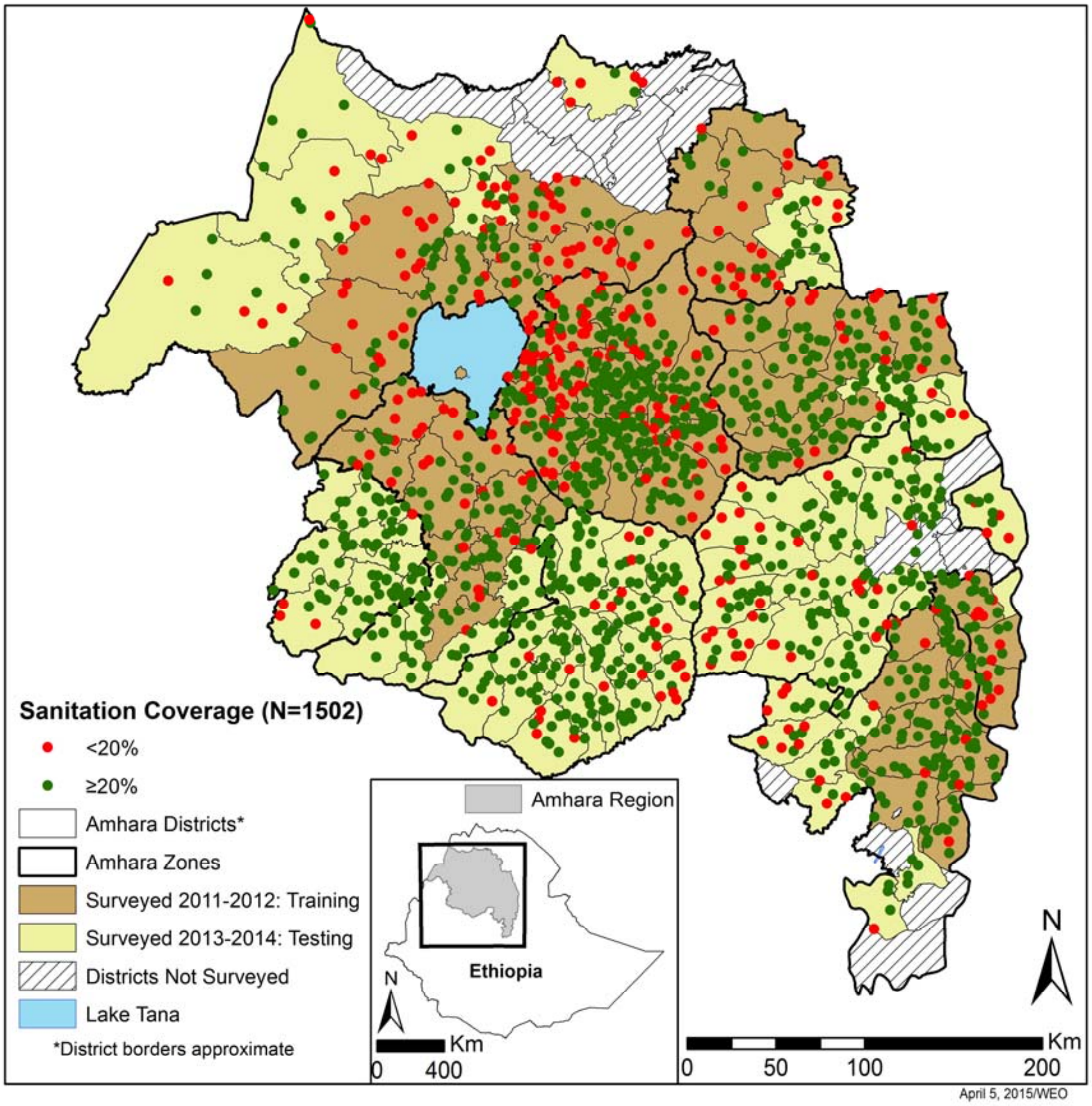

Figure 7.2 Distribution of surveyed woreda by training or testing dataset, and low community sanitation coverage in Amhara Region, Ethiopia, 2011-2014.

Table 7.2 Environmental and social conditions of communities in Amhara Region, Ethiopia, 2011-2014.

Characteristic	Training: Surveyed 2011-2012 (n=876) Median	(IQR)	N	(%)	Testing: Surveyed 2013-2014 (n=626) Median	(IQR)	N	(%)	Complete: Surveyed 2011-2014 (n=1502) Median	(IQR)	N	(%)
Sanitation coverage <20%			228	26.03			116	18.53			344	22.90
USDA soil texture classes												
Clay			200	22.83			226	36.10			426	28.36
Clay loam			302	34.47			210	33.55			512	34.09
Loam			138	15.75			102	16.29			240	15.98
Sandy clay loam			236	26.94			88	14.06			324	21.57
High soil gravel content			371	42.35			263	42.01			634	42.21
Annual mean NDVI 2011	0.41	(0.35, 0.46)			0.44	(0.39, 0.49)			0.42	(0.37, 0.47)		
Surface land form category												
Smooth plains			48	5.48			30	4.79			78	5.19
Irregular plains			174	19.86			165	26.36			339	22.57
Escarpment			40	4.57			25	3.99			65	4.33
Hills			22	2.51			15	2.40			37	2.46
Breaks			147	16.78			90	14.38			237	15.78
Low mountains			394	44.98			257	41.05			651	43.34
High mountains/Deep valleys			51	5.82			44	7.03			95	6.32
Percent slope (%)	5.77	(2.93, 11.26)			6.08	(2.48, 12.67)			5.88	(2.72, 11.64)		
Altitude (m)	2222	(1917, 2633)			2277	(1936, 2598)			2241	(1927, 2614)		
Low-lying land			35	4.00			24	3.83			59	3.93
Annual total rainfall (mm)	1126	(1008, 1349)			1155	(998, 1421)			1138	(1004, 1371)		
Distance to nearest road (km)	4.41	(1.45, 9.20)			4.10	(1.41, 7.87)			4.30	(1.43, 8.57)		
Population per km^{-2} 2011	116.72	(56.05, 277.85)			107.26	(55.88, 305.59)			113.53	(56.05, 289.44)		
Community mean total wealth indicators	0.73	(0.31, 1.07)			1.13	(0.83, 1.57)			0.93	(0.49, 1.30)		
Time since July 2011 (yr)												
0			353	40.30			0	0.00			353	23.50
0.8			208	23.74			0	0.00			208	13.85
1.4			315	35.96			0	0.00			315	20.97
1.9			0	0.00			356	56.87			356	23.70
2.5			0	0.00			270	43.13			270	17.98
Rainy season			561	64.04			356	56.87			917	61.05

Table 7.3 Candidate training models for predicting community sanitation coverage <20% among communities in Amhara Region, Ethiopia, 2011-2012.

Model	Intercept	Altitude	Annual Rainfall	High Gravel	Pop. Density	Low-lying Land	Clay	Clay Loam	Loam	NDVI	Distance to Road	Slope	Time	Rainy	Δ_i¥	ω_i
1	+X*	-X*	-X*	+X^{NS}	-X*	+X*	--	--	--	--	--	--	+X	+X*	0.00	**0.22**
2	+X*	-X*	-X*	--	-X*	+X*	-X^{NS}	+X^{NS}	+X^{NS}	--	--	--	+X*	+X*	0.86	**0.14**
3	+X*	-X*	-X*	+X^{NS}	-X*	+X*	--	--	--	-X^{NS}	--	--	+X	+X*	0.88	**0.14**
4	+X*	-X*	-X*	--	-X*	+X*	--	--	--	--	--	--	+X	+X*	0.91	**0.14**
5	+X*	-X*	-X*	--	-X*	+X*	-X^{NS}	+X^{NS}	+X^{NS}	-X^{NS}	--	--	+X*	+X*	1.61	**0.10**
6	+X	-X*	-X*	+X^{NS}	-X*	+X*	--	--	--	--	+X^{NS}	--	+X	+X*	1.78	**0.09**
7	+X*	-X*	-X*	--	-X*	+X*	--	--	--	-X^{NS}	--	--	+X	+X*	1.89	**0.09**
8	+X*	-X*	-X*	+X^{NS}	-X*	+X*	--	--	--	--	--	+X^{NS}	+X	+X*	1.93	**0.08**
$\sum\omega_i(j)$	**1.00**	**1.00**	**1.00**	**0.53**	**1.00**	**1.00**	**0.24**	**0.24**	**0.24**	**0.32**	**0.09**	**0.08**	**1.00**	**1.00**		

Symbols: X (variable tested in model); -- (variable not tested in model); - (negative association); + (positive association); *($p \leq 0.01$); NS (not significant); $\Delta_i = AIC_i - AIC_{min}$; $\omega_i = \exp(-1/2\ \Delta_i)/\sum \exp(-1/2\ \Delta_i)$; $\sum\omega_i(j)$ = sum of ω_i values from all models in which variable i was present.

¥AIC_{min} = 880.29

Table 7.4 Logistic regression models for predicting sanitation coverage <20% among communities in Amhara Region, Ethiopia, 2011-2014.

	Selected & Validated Model					Selected Model + Community Wealth				
Parameters (unit of change)	**Coeff.**	**SE**	**p**	**OR**	**(95% CI)**	**Coeff.**	**SE**	**p**	**OR**	**(95% CI)**
Intercept	3.54	0.52	<0.01	--	--	2.84	0.53	<0.01	--	--
High gravel content (yes/no)	0.56	0.16	<0.01	1.76	(1.28, 2.41)	0.46	0.16	<0.01	1.58	(1.15, 2.19)
Low-lying land (yes/no)	1.01	0.31	<0.01	2.74	(1.49, 5.02)	1.04	0.31	<0.01	2.82	(1.53, 5.20)
Population per km^{-2} 2011 ($\log_{10}$)	-0.55	0.11	<0.01	0.58	(0.46, 0.73)	-0.19	0.13	0.14	0.83	(0.64, 1.07)
Altitude (100 m)	-0.08	0.02	<0.01	0.92	(0.89, 0.95)	-0.09	0.02	<0.01	0.91	(0.88, 0.94)
Annual total rainfall (100 mm)	-0.21	0.04	<0.01	0.81	(0.75, 0.88)	-0.16	0.04	<0.01	0.85	(0.79, 0.92)
Community mean total wealth indicators (+1)	--	--	--	--	--	-0.86	0.14	<0.01	0.42	(0.32, 0.55)
Time since July 2011 (yr)	-0.20	0.10	0.04	0.82	(0.68, 0.99)	0.05	0.10	0.66	1.05	(0.85, 1.28)
Rainy season (yes/no)	0.95	0.22	<0.01	2.59	(1.69, 3.96)	1.10	0.23	<0.01	3.00	(1.93, 4.66)

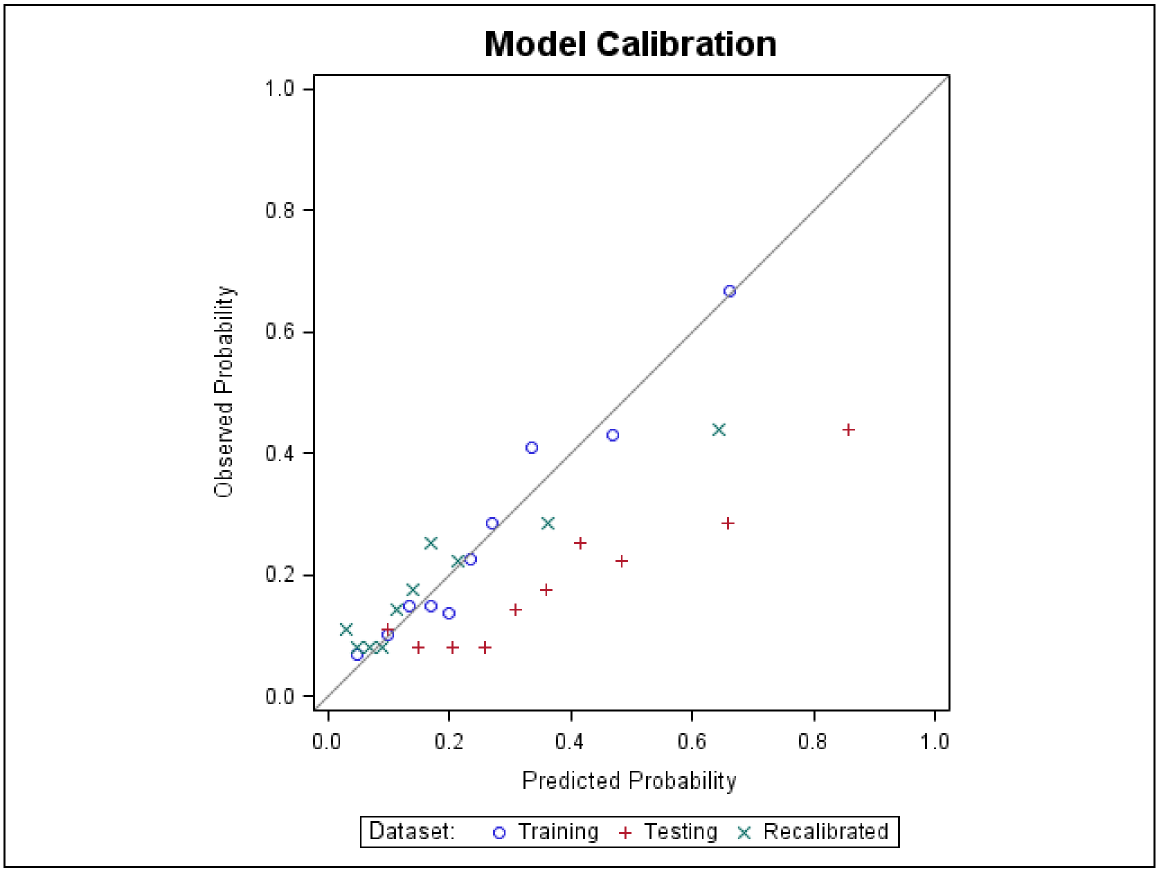

Figure 7.3 Observed versus predicted probabilities for low sanitation coverage by deciles of predicted probability for models applied to training and testing datasets.

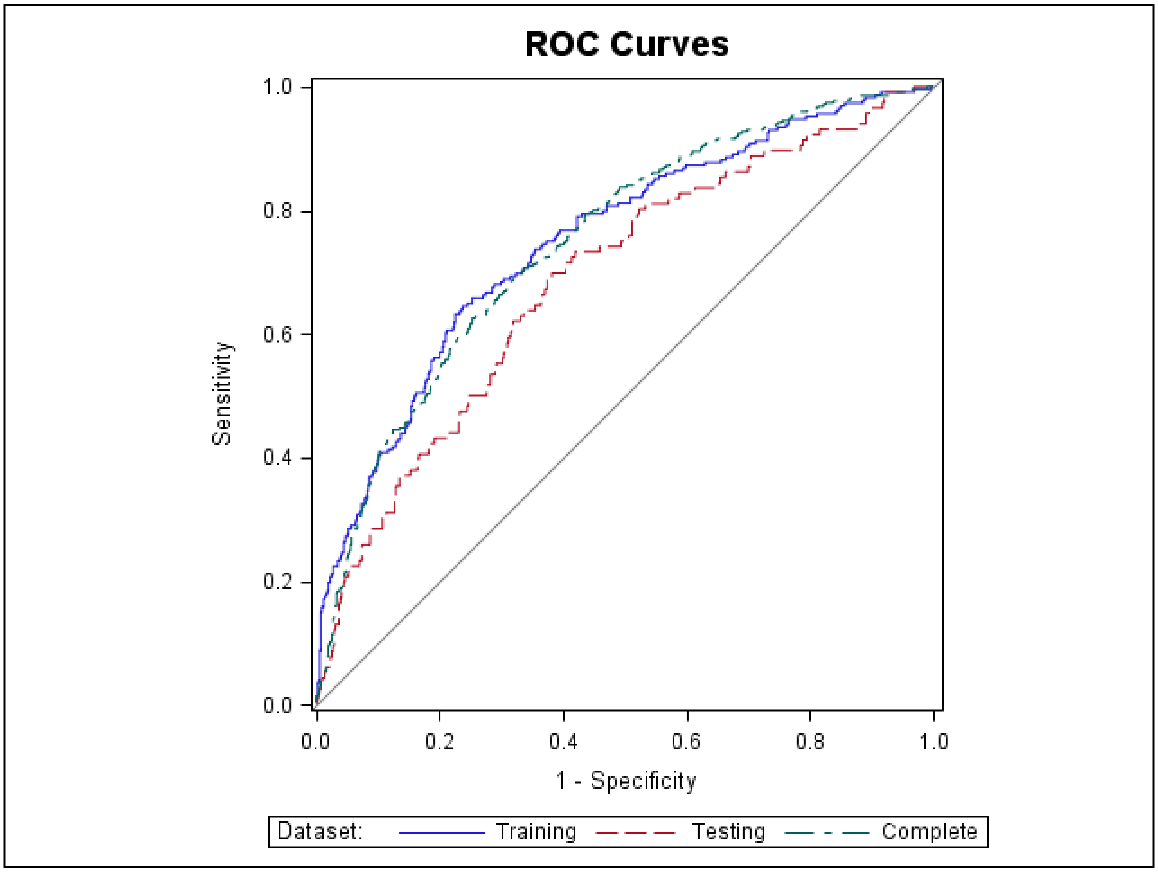

Figure 7.4 Receiver-operator curves showing sensitivity versus 1-specificity for models applied to training, testing and complete datasets.

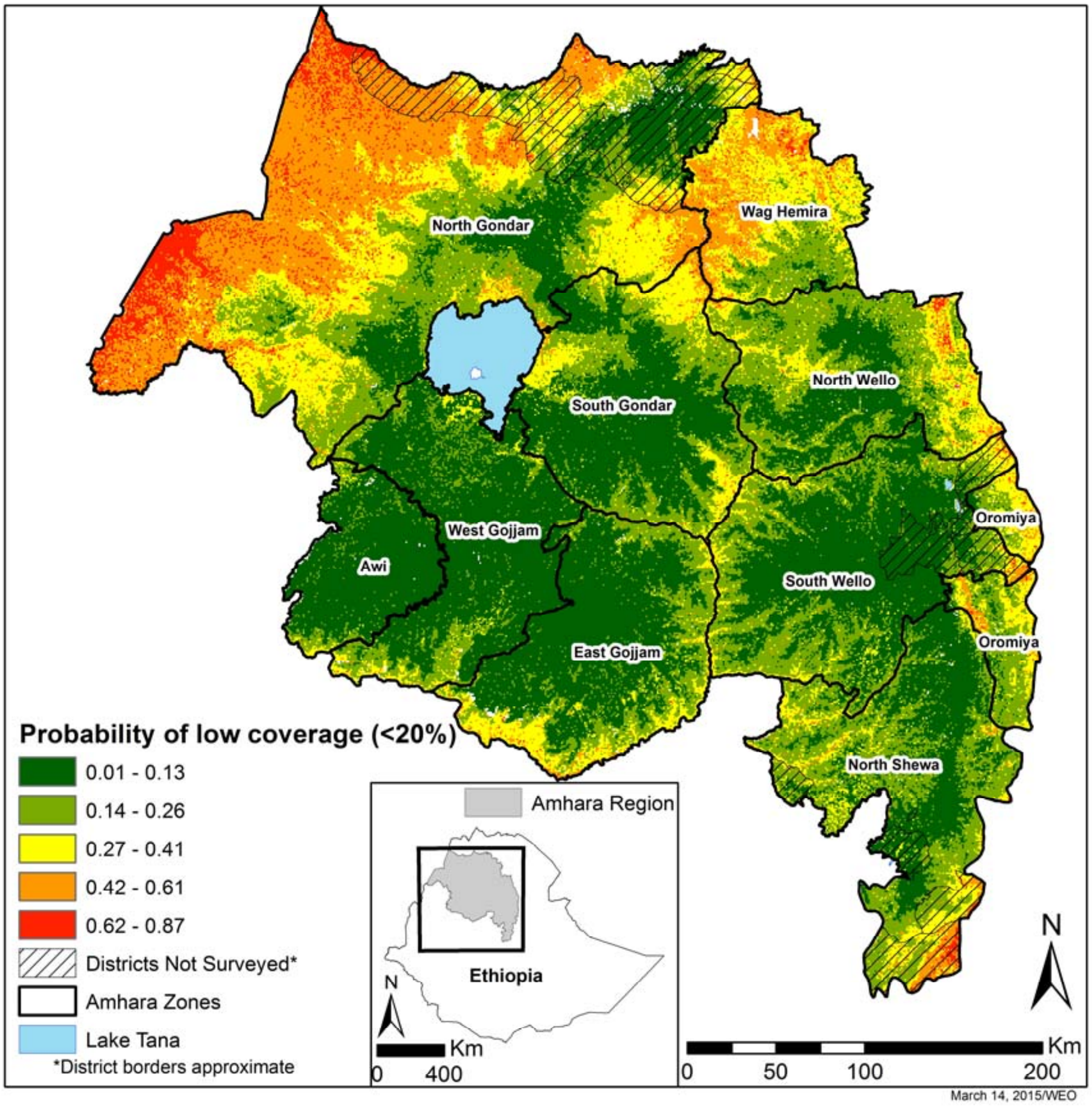

Figure 7.5 Map of model-predicted probability of low community sanitation coverage (<20%) in Amhara Region, Ethiopia, 2011-2014, based on selected environmental and social factors and adjusted for survey season and year.

Table 7.5 Generalized estimating equation logistic regression models for predicting sanitation coverage <20% among communities in Amhara Region, Ethiopia, 2011-2014.

	Selected Model					Selected Model + Community Wealth				
Parameters (unit of change)	**Coeff.**	**SE**	**p**	**OR**	**(95%CI)**	**Coeff.**	**SE**	**p**	**OR**	**(95%CI)**
Intercept	3.20	0.78	<0.01	--	--	2.37	0.81	<0.01	--	--
High gravel content (yes/no)	0.55	0.18	<0.01	1.74	(1.21, 2.50)	0.41	0.19	0.027	1.51	(1.05, 2.18)
Low-lying land (yes/no)	0.91	0.23	<0.01	2.47	(1.58, 3.87)	0.90	0.21	<0.01	2.47	(1.62, 3.75)
Population per km^{-2} 2011 (log$_{10}$)	-0.62	0.12	<0.01	0.54	(0.43, 0.68)	-0.27	0.14	0.043	0.76	(0.58, 0.99)
Altitude (100 m)	-0.07	0.02	<0.01	0.93	(0.89, 0.97)	-0.07	0.02	<0.01	0.93	(0.89, 0.97)
Annual total rainfall (100 mm)	-0.18	0.06	<0.01	0.83	(0.74, 0.93)	-0.13	0.06	0.021	0.88	(0.79, 0.98)
Community mean total wealth indicators (+1)	--	--	--	--	--	-1.00	0.16	<0.01	0.37	(0.27, 0.50)
Time since July 2011 (yr)	-0.21	0.15	0.16	0.81	(0.61, 1.08)	0.09	0.16	0.566	1.1	(0.80, 1.52)
Rainy season (yes/no)	0.84	0.30	<0.01	2.32	(1.29, 4.20)	1.01	0.32	<0.01	2.74	(1.45, 5.17)

Chapter 8 - Conclusion

The first two studies of this dissertation examined the relationship between community sanitation and prevalence of disease among children in Amhara Region, Ethiopia. Specifically, the first study aimed to estimate the association between community sanitation usage, the proportion of households in a community with latrines in use, and active trachoma among children, aged 1 to 9 years, following 5 years of SAFE implementation. The second study aimed to estimate the association between community sanitation usage and infection with the soil-transmitted helminths: *Ascaris lumbricoides* (AL), *Trichuris trichiura* (TT), and hookworm (HW), among children, aged 6 to 15 years. For both of these studies, it was hypothesized that increased community sanitation usage, and inversely the amount of open defecation in the community, would be associated with lower prevalence of disease.

Towards these aims, a multilevel approach was utilized to examine the relationship between this contextual measure of sanitation and individual occurrence of the disease, accounting for factors at the community, household, and individual level (167). Data were combined from five SAFE impact surveys conducted in distinct areas of Amhara between 2011 and 2014 by the Amhara Regional Health Bureau and The Carter Center's Trachoma Control Program. SAFE impact surveys were designed to provide population-based estimates of trachoma and STH infection prevalence. A large sample size allowed for greater flexibility for the current analyses, and study conclusions were strengthened by the representativeness of the selected sample. The application of multilevel modeling to large scale, complex survey data is a relatively new approach (114). The multilevel analysis implemented here was further strengthened by the modified segment method utilized by the SAFE impact surveys for data collection. Each selected community was first divided into geographic segments, one of which was randomly selected, and all households within the segment were surveyed (107, 108). With this design, the community measure for our exposure of interest was based on an actual physical aggregation of households, or "compact cluster," providing a true group-level construct of living conditions, beyond the household level, for each child (108). Alternatively, randomly selecting households within the entire community would also have provided an estimate of community conditions, but not necessarily the conditions most proximate to each child. The ability to draw causal inferences is improved by better specification of group-level factors (167). Multilevel analysis also allowed for quantification of variance at each level of analysis (168).

The first analysis found that prevalence odds of active trachoma among children in communities with sanitation usage of 60-<80% and ≥80% were lower and significantly lower, respectively, compared to children in communities with sanitation usage <20%. This result was summarized across strata of the household's water and latrine access to account for statistically significant multiplicative interaction. These results suggest that increasing the proportion of households in a community with latrines in use is protective against active trachoma amongst children aged 1 to 9 years, independent of whether or not a child's household had a latrine in use or better access to water and controlling for other individual, household, and community factors. A measure of residual variation, median odds ratio, indicated that substantial variation in prevalence odds remained at household and community levels, even after controlling for other factors. This information highlighted the possibility of residual confounding. Based on this finding, it was recommended that specific indicators of hygiene behavior be collected in future studies of trachoma prevalence in this region. Future analyses may also be strengthened by incorporating methods to account for spatial autocorrelation.

In contrast to the results observed for trachoma, the second analysis found no evidence that increased community sanitation usage was protective against the three most-common STH infections among children aged 6-15 years in Amhara Region, Ethiopia. After adjusting for potential confounders, no association was detected between community sanitation usage and prevalence of HW infection. A possible explanation for this finding was that, in the absence of widespread anthelmintic treatment, prevalence might not have declined since the installation of pit latrines because of HW's long lifespan within the gut (41).

More counterintuitive to expectation was the finding of significantly higher prevalences of TT infection among children from communities with sanitation usage of 60-<80% and ≥80%, compared to children from communities with usage <20%. Prevalence of TT was very low overall, but our limited measure of infection intensity also showed a similar and significant pattern, which may reflect increasing transmission with higher community sanitation usage. There was some indication of residual confounding of the relationship of TT with community sanitation usage, so coexisting differences in hygiene and diet or other unmeasured contextual factors should be examined with future work.

The association of community sanitation usage with AL prevalence followed similar patterns as TT infection, but was also significantly modified by household latrine usage, adjusting for all covariates. Community sanitation usage was not significantly associated with AL prevalence among children from households with a latrine in use. Prevalence of AL infection was higher among children from households without a latrine in use in communities with higher sanitation usage, compared to children from households without a latrine in communities with usage <20%. This latter finding reflected the possibility that unmeasured domestic conditions of these children in households last to adopt sanitation, in communities with high usage, were contributing to elevated prevalence.

Overall, these studies indicated that a possible threshold of community sanitation usage exists at which prevalence of active trachoma begins to decline, within the context of five years of SAFE implementation. Though conclusions are limited by our categorization of the measure, 60% community sanitation usage might be a reasonable minimum for trachoma control activities at which declines in prevalence could be expected. Further reductions in prevalence were clearer at usage of ≥80%, strengthening support for this as a sanitation target for achievable health gains. These results should be confirmed by other studies, however, before this figure is set as a defined target. Furthermore, both levels are well below the ideal of 100% usage and may not correspond to the relationship between community sanitation usage and other diseases. For example, the counterintuitive results from our study indicate that the relationship between community sanitation usage and STH infection is not fully understood. Regardless, the findings highlight the importance of considering community sanitation as a context when examining the occurrence of individual disease.

Beyond community sanitation, other recent studies have also demonstrated the influence of contextual measures on STH infection and active trachoma. Schule *et al.* found a significant association between mean annual rainfall and land surface temperature and infection with *Ascaris lumbricoides* in Tanzania (98). Riess *et al.* found a significant association between land surface temperature and enhanced vegetation index with hookworm infection in Tanzania (97). The authors of both studies recognized the limitation of not examining soil composition. Including these factors in our models might have further clarified the relationship between community sanitation and STH infection prevalence and is an important next step. In their systematic review, Ramesh *et al.* described the potential influence of climactic factors, particularly temperature and rainfall, on the distribution and prevalence of trachoma (169). Including these factors, or a proxy measure for temperature such as altitude, may have controlled for additional variability across this large study area and in turn strengthened the observed association of community sanitation usage with trachoma prevalence.

Much of the evidence of the relationship between improved living conditions and reductions in trachoma and STH infection is based on observational risk factor studies of limited quality that focused on household sanitation (50, 130). Furthermore, randomized, controlled trials examining the relationship between improved sanitation and active trachoma and STH infection have also proved inconclusive with respect to health impacts

(37, 38, 170, 171). Further research studies are needed to examine the intricate relationships between sanitary and hygiene behaviors, environmental and social contexts, and trachoma and STH transmission, particularly within the context of large-scale treatment programs. Multilevel analysis is a powerful tool allowing for simultaneous investigation of environmental, community, household, and individual factors, and when applied to program evaluation data in the current studies provided further information on the complex interaction between context and disease.

Recognizing the potential influence of environmental and social conditions on occurrence of low sanitation coverage, the third study aimed to develop and validate a diagnostic model for estimating the probability of a community having low sanitation coverage based on these factors. For this study, the same set of data was used as in the first two studies. Instead of modeling individual disease, however, the outcome for this aim was a dichotomous indicator of whether or not the community proportion of households with a latrine was less than 20%. Whether or not latrines were in use was not considered because usage may influence latrine maintenance and *vice versa*, and the aim was to explore contextual determinants of ownership, excluding behavioral factors. Information on environmental predictors was collected from existing data sources, publicly available on the Internet. Because the interest was not only in developing a predictive model but also in validating its performance, the survey dataset was split into a training dataset, using surveys conducted between 2011 and 2012, and a testing dataset, using surveys conducted between 2013 and 2014. This division allowed for both geographic and temporal validation of the model. The model-building approach attempted to maximize model fit, while maintaining needed control variables.

The selected model showed reasonable calibration and discrimination using the training dataset, but the model performed less well when applied to the testing dataset. Supplementary re-calibration reduced model over-prediction when applied to the testing dataset. When applied to the combined dataset, the final model was well calibrated and had a reasonable discrimination ability. The estimated coefficients from this model were then used to generate a map of predicted risk of poor sanitation coverage across Amhara Region based on the environmental and social conditions in each location.

As with the other aims, the findings from this study are strengthened by the size and representativeness of the dataset. The large dataset, combining five years of survey data collected throughout the Amhara Region, could be divided both temporally and geographically to validate the model's ability to predict low sanitation coverage. The assessment of household latrine ownership was visually confirmed, and this measure was aggregated to the community. As such, there is little likelihood of misclassification. The study's conclusions, however, are potentially limited by the accuracy of the obtained data on environmental and social predictors, particularly at the scale at which it was utilized. Even so, the model maintained reasonably good discrimination ability.

The relationships between landscape, climate, and soil behavior are very complex, and the predictive model for poor sanitation coverage necessarily oversimplified the involved mechanisms leading to latrine pit collapse. While some of the environmental measures, such as rainfall and altitude are applicable to other areas, the modeled measures for soil conditions only included values observed in Amhara, which limits the applicability of the estimated model to other regions. The use of continuous measures for soil percentages of sand, silt, clay and gravel was avoided because of concerns about accuracy, but a single slope for these factors would have allowed for more universal application. Future applications of this approach should also consider including the major soil group classifications (159). These classifications combine multiple aspects of soil characterization, however, and the mechanistic relationship with latrine pit collapse is less clear. One soil group in particular is known to lead to structural difficulties and contributes to soil collapse. Vertisols, constituting the "black cotton" soils common throughout South Sudan and parts of Ethiopia, have high clay content but are expansive in nature and have a high collapse risk (157). The current study might have been strengthened by exploring the inclusion of an indicator for this soil group to potentially better characterize the risk of soil collapse. The approach demonstrated in the third study provides a useful tool for disease control and sanitation programs to identify areas in need of additional or alternate sanitation interventions. It should be replicated, and developed models can be updated and revised to incorporate new or additional information on environmental and social predictors as they become available.

By applying social epidemiologic and predictive modeling methods to a unique set of program evaluation data combined with a geographic information system with environmental and social data, this dissertation furthers understanding of the relationship between sanitation and two of the most common NTDs and mechanisms leading to geographic heterogeneity in sanitation coverage. For all three of its aims, this dissertation identified next steps for future research and will assist organizations working on water, sanitation, and hygiene and NTD control programs to better serve their target populations.

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Appendix 1 – IRB Documentation

EMORY UNIVERSITY | Institutional Review Board

April 29, 2014

Will Oswald, PhD Candidate
Emory University
Rollins School of Public Health

RE: Determination: No IRB Review Required
Title: Paper Study Number 079-2006 Title: *Evaluation of national trachoma control programs supported by the Carter Center in Sudan, Ethiopia, Mali, Niger, Ghana and Nigeria*

Dear Mr. Oswald:

Thank you for requesting a determination from our office about the above-referenced project. Based on our review of the materials you provided, we have determined that it does not require IRB review because it does not meet the definition(s) of "research" involving "human subjects" as set forth in Emory policies and procedures and federal rules, if applicable. Specifically, in this project, you will conduct secondary analyses of data that The Carter Center's Trachoma Control Program collected to evaluate the impact of the SAFE (Surgery, Antibiotic treatment, promotion of Facial cleanliness and hygiene, and Environmental improvement) intervention in Sudan, Ethiopia, Mali, Niger, Ghana and Nigeria. Your secondary data analyses will focus on the data collected in Amhara, Ethiopia. The results from this study, by describing the conditions four years after an intervention and identifying possible causes of these conditions, will help improve current community-based efforts to increase access to household sanitation and personal hygiene in Ethiopia. This project is public health practice.

Please note that this determination does not mean that you cannot publish the results. If you have questions about this issue, please contact me.

This determination could be affected by substantive changes in the study design, subject populations, or identifiability of data. If the project changes in any substantive way, please contact our office for clarification.

Thank you for consulting the IRB.

Sincerely,

[redacted]

Carol Corkran, MPH, CIP
Interim Team Lead

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