Distribution Agreement

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, now or hereafter known, including display on the world-wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature:

_____ _____

Lisa Emerson April 24. 2019

WASH Factors and Leprosy Schistosomiasis Co-Infections in North Gondar, Ethiopia: Risk Factors for Leprosy Transmission

By

Lisa Emerson

Master of Science in Public Health

Global Epidemiology

_____

Dr. Matthew Freeman

Committee Chair

_____

Dr. Jessica Fairley

Committee Member

WASH Factors and Leprosy Schistosomiasis Co-Infections in North Gondar, Ethiopia: Risk Factors for Leprosy Transmission

By

Lisa Emerson

Bachelor of Science

Clemson University

2016

Faculty Thesis Advisor: Dr. Matthew Freeman, MPH, PhD

Faculty Field Advisor: Dr. Jessica Fairley, MD, MPH

An abstract of

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University

in partial fulfillment of the requirements for the degree of
Master of Science in Public Health

2019

Abstract

WASH Factors and Leprosy Schistosomiasis Co-Infections in North Gondar, Ethiopia: Risk Factors for Leprosy Transmission

By Lisa Emerson

Access to safe water, sanitation, and hygiene (WASH) is critical for preventing the spread of many neglected tropical diseases (NTDs). While leprosy is thought to be transmitted primarily through nasal secretions from infected individuals, WASH-related transmission factors remain largely unexplored as part of the leprosy transmission cycle. The aim of this project is to better understand WASH exposures among leprosy cases through a case-control study in the North Gondar district of Ethiopia, an area endemic to leprosy and other NTDs. We hypothesize that leprosy cases are more likely to have inadequate access to safe WASH and are more likely to have concurrent schistosomiasis, as schistosomiasis immune consequences may facilitate leprosy infection. Adult leprosy cases and controls without leprosy were recruited from health districts in the North Gondar region and tested for *Schistosoma mansoni* with a point-of-care test. All participants answered a demographic and WASH survey. Participants were assigned a WASH index score using WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) core questions on WASH for household surveys. Eighty-one persons were enrolled with a median age of 33, of whom 75% were male. The majority of the 40 cases had multibacillary disease (83%) and *S. mansoni* infection was detected in 26% of participants. WASH factors associated with leprosy on adjusted analyses showed an association with open defecation (OR=19.9, 95% CI 2.2, 176.3) and lack of access to soap (OR=7.3, 95% CI (1.1, 49.9); but were inconclusive for improved water source (OR=3.5, 95% CI 0.31, 38.8), lack of water treatment (OR=0.28, 95% CI 0.04, 1.8), time to fetch water (OR=0.99, 95% CI 0.93, 1.1), and lack of handwashing (OR=2.5, 95% CI 0.47, 12.8). In the stratified analysis, those with leprosy had a 3.6, 95% CI (0.8, 15.9), greater odds of schistosomiasis in districts bordering the lake, while those with leprosy had 0.33 lower odds of schistosomiasis in districts not bordering the lake 95% CI (0.09, 1.2). Overall, these results suggest that leprosy transmission may be related to WASH adequacy and access as well as schistosomiasis co-infection.

WASH Factors and Leprosy Schistosomiasis Co-Infections in North Gondar, Ethiopia: Risk Factors for Leprosy Transmission

By

Lisa Emerson

Bachelor of Science

Clemson University

2016

Faculty Thesis Advisor: Dr. Matthew Freeman, MPH, PhD

Faculty Field Advisor: Dr. Jessica Fairley, MD, MPH

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University

in partial fulfillment of the requirements for the degree of
Master of Science in Public Health

2019

Table of Contents

Chapter I: Literature Review

Neglected Tropical Diseases

Neglected tropical diseases (NTDs) are a group of communicable diseases defined by the World Health Organization (WHO) that are present in 149 countries globally. NTDs infect over one billion people and include several diverse diseases including: Buruli ulcer, Chagas disease, Dengue, Chikungunya, Dracunculiasis, Echinococcosis, Foodborne trematodiases, Human African Trypanosomiasis, Leishmaniasis, Lymphatic filariasis, Mycetoma/chromoblastomycosis, Onchocerciasis, Rabies, Scabies, Soil-transmitted helminths, Snakebite envenoming, Taeniasis/Cysticercosis, Trachoma, Yaws, Schistosomiasis, and Leprosy. These diseases are disproportionately prevalent in low and middle-income countries (LMICs), with the greatest disease burden in populations living in poverty (1) .

In 2007, WHO published the "Global Plan to Combat Neglected Tropical Diseases 2008-2015," which outlines goals to prevent, control, eliminate, and eradicate diseases based on the resolutions of the World Health Assembly and regional offices and is WHO's first plan to combat NTDs (2). In 2012 WHO published *Accelerating Work to Overcome the Global Impact of Neglected Tropical Diseases: A Roadmap for Implementation* which lays out NTD strategies as well as targets for 2012-2020 for each of the NTDs for prevention, control, elimination, or eradication. WHO recommends five strategies to reach these goals including: preventive chemotherapy; intensified disease management; vector and intermediate host control; veterinary public health at the human-animal interface; and provision of

safe water, sanitation, and hygiene (WASH) (3). This roadmap identifies WHO accepted methods of treatment and prevention for each of the NTDs.

The NTD Roadmap spans the 2015 transition from the Millennium Development Goals (MDGs) to the Sustainable Development Goals (SDGs). While the MDGs were meant to include many major communicable diseases, they only mention HIV/AIDs and malaria by name under MDG 6. While NTDs were recognized as barriers to development prior to the creation of the MDGS, they were not named directly and fell under the "other diseases" portion of MDG 6 (4,5). With NTDs comprising a large amount of disease burden globally but only receiving 0.6% of health development assistance globally, NTDs are now included in the SDGs under SDG 3: "Ensure healthy lives and promote well-being for all at all ages" within target 3.3: "By 2030, end the epidemics of AIDS, TB, malaria and neglected tropical diseases (NTDs) and combat hepatitis, water-borne diseases and other communicable diseases," and indicator 3.3.5: "number of people requiring interventions against neglected tropical diseases (6–8)."

Beyond SDG target 3.3, NTDs fall into targets 3.8, 6.1, and 6.2 (7). Target 3.8 is to "achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all," and preventive chemotherapy, an NTD control and prevention strategy, is considered an essential health-care service, while the preventive chemotherapies are incorporated as essential medicines (7,8). Several NTDs will be mitigated with improvements to WASH under

targets 6.1 and 6.2: “By 2030, achieve universal and equitable access to safe and affordable drinking water for all” and “By 2030 achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations,” as several NTDs are susceptible to WASH improvements and provision of safe WASH is a WHO NTD management strategy (7,9).

NTDs can be considered indirectly under many SDGs including SDG 1 (no poverty), 2 (zero hunger), 4 (quality education), and 13 (climate action) as well, but are only named directly under target 3.3 (8) . This underscores the complexities of the NTD group as well as the need for integrated strategies to combat them, especially considering overlapping vulnerabilities of populations to multiple diseases (10). Africa, in particular, accounts for 40% of the global NTD burden and WHO AFRO region focuses interventions on 11 NTDs that have the greatest burden in the region, including schistosomiasis and leprosy (11).

Schistosomiasis

Schistosomiasis is a parasitic NTD caused primarily by *Schistosoma mansoni, S. haematobium, and S. japonicum* and less commonly by *S. mekongi* and *S. intercalatum*. Schistosomiasis is transmitted via cercariae in contaminated water, which are released from aquatic freshwater snails. A person becomes infected with schistosomiasis by skin contact with contaminated water, typically through swimming, bathing, wading, and washing (12). Symptoms of schistosomiasis include rash and itching initially and subsequent hematuria, fever, chills, cough, myalgia,

abdominal pain, diarrhea, hematochezia, liver enlargement, genital lesions, vaginal bleeding, and pain during intercourse. Interestingly these symptoms are caused by the eggs rather than the adult worms (13). Symptoms often differ with the causative agents of schistosomiasis. Among the three most prevalent types of schistosomiasis, *S. haematobium* infections typically reside in the bladder, *S. mansoni* in the large intestine, and *S. japonicum* in the small intestine (14). Once in the intestine or bladder the female worms will shed eggs, which are released through stool or urine into the environment (15).

Geographically, *Schistosoma* species are found throughout much of the world. *S. japonicum* is distributed across Indonesia as well as parts of China and Southeast Asia. *S. haematobium* is found throughout the African continent, primarily in southern and sub-Saharan Africa. Finally, *S. mansoni* is also endemic throughout southern and sub-Saharan Africa, South America, and at low risk on several Caribbean islands (16).

Schistosomiasis is typically diagnosed through microscopy; eggs are visualized in either stool or urine samples. Additionally, diagnosis of *S. mansoni* infections can be done through smears via the Kato Katz technique and a urine dipstick testing the schistosome circulating cathodic antigen (17,18). Serology can be used for all types of schistosomiasis; however, this is only of use for travelers or non-endemic areas, as any history of schistosomiasis infection will produce a positive serologic test (12). All varieties of schistosomiasis can be treated with praziquantel (12).

Schistosomiasis can be prevented and controlled through mass drug administration (MDA) (13). The MDA, or preventive chemotherapy, strategy involves periodic treatment of at-risk groups with praziquantel. Typically, this includes school-aged children in endemic areas, adults who often come into contact with contaminated water, and entire communities in high burden areas. WASH improvements and vector control of snails can also be employed to control the spread of schistosomiasis (13).

Leprosy

Leprosy, also known as Hansen's disease, is a chronic infectious disease, caused by *Mycobacterium leprae*, classified as a NTD by WHO (19). WHO defines a leprosy case as a person with one or more of the following symptoms: hypopigmented or reddish skin lesions with a loss of sensation; damage to the peripheral nerves, assessed by a loss of sensation and hand, feet, or face mobility; positive skin smear tests (20). Diagnosis of leprosy is defined by WHO as one or more of the following signs of infection: "(i) definite loss of sensation in a pale (hypopigmented) or reddish skin patch, (ii) thickened or enlarged peripheral nerve with loss of sensation and/or weakness of the muscles supplied by that nerve, or (iii) presence of acid-fast bacilli in a slit-skin smear." Further laboratory assays and histopathologic examinations exist to confirm clinical diagnosis, however, these can be prohibitive in basic primary care settings. These methods include lateral flow assays, PCR-based assays, and enzyme-linked immunosorbent assays (21).

Leprosy can cause disfigurement and disability, particularly to the hands, feet, and eyes. This disability is graded upon diagnosis using the following grading strategy: for hands and feet, grade 0 indicates no anesthesia and no visible deformity or damage; grade 1 indicates anesthesia present, but without visible deformity or damage; grade 2 indicates visible deformity or damage present. For the eyes: grade 0 indicates no eye problem due to leprosy and no evidence of visual loss; grade 1 indicates eye problems due to leprosy are present, but vision is not severely affected as a result; and grade 2 indicates severe visual impairment as well as lagophthalmos, iridocyclitis, and corneal opacities (22).

Leprosy is treated with a 3-drug regimen that includes rifampicin, dapsone, and clofazimine. WHO recommends treatment for 6 months for paucibacillary leprosy cases and 12 months for multibacillary leprosy cases. Several regimen modifications exist for leprosy cases that exhibit antibiotic resistance or intolerance (23). Since close contact with a leprosy patient is a risk factor for transmission, WHO recommends a single dose of rifampicin for children and adults over 2 years of age. However, this can only be administered after excluding current leprosy and tuberculosis infection. Concerns with stigma and antibiotic resistance remain for prophylactic treatment, however. Close contact with a leprosy case is a risk factor, but the degree of contact that warrants prophylactic treatment is not well understood (24).

In WHA51.15, published in 1998, the World Health Assembly resolved to eliminate leprosy as a global health problem by 2000. This resolution was achieved

and lowered leprosy prevalence to less than 1/10,000 people worldwide; however, the burden still varies substantially within regions and countries (25). While it is considered to be eliminated as a global health problem, many countries are still struggling to eliminate the disease within their borders with 22 countries reporting over 94% of new cases. In order to create a global plan, WHO, working closely with the Regional Office for South-East Asia, published the "Global Leprosy Strategy 2016-2020, accelerating towards a leprosy-free world (26)." The three main targets in this document are: to have zero pediatric leprosy patients with grade two disabilities, to reduce the number of new leprosy cases with grade two disabilities to less than 1/1,000,000, and to have no countries with legislation allowing for discrimination on the basis of leprosy status (26)."

Epidemiology

For the year 2017, The Institute for Health Metrics and Evaluation (IHME) estimates the overall global NTD burden to be 815.12 DALYs per 100,000 with a 95% CI of (635.52, 1045.1). High socio-demographic index (SDI) countries, however, have a burden of 21.01 DALYs per 100,000, 95% CI (14.01, 28.99). In comparison, Ethiopia's overall NTD burden is slightly less than the global total: 728.08 DALYs per 100,000 with a 95% CI of (508.17, 1,007.16)(27). Of note, this estimate excludes newly added NTDs including chromoblastomycosis and snakebite envenoming, which WHO added to the list in 2017 (1).

IHME estimates the schistosomiasis burden to be 18.74 DALYs per 100,000, 95% CI (11.47, 31.89). Ethiopia's schistosomiasis burden is much higher than the

average global burden at 173.31, 95% CI (96.91, 320.01), DALYs per 100,000. In contrast, high SDI countries experience a loss of 0.00062, 95% CI (0.00036, 0.00096) DALYs per 100,000 (27). Of note, these estimates include all types of schistosomiasis and are not limited to *S. mansoni.* WHO estimates that 206.4 million humans require preventative chemotherapy across 52 countries (13).

In 2017, 210,671 new leprosy cases were diagnosed around the world. This is equivalent to 2.77 cases per 100,000 people. In Ethiopia, WHO was notified of 3114 new cases, which represents a decrease in number of diagnosed new cases. In 2013, 4374 new cases were diagnosed and in 2015 there were 3970 (28). IHME estimates a burden of 0.41 DALYs per 100,000 95% CI (0.28, 0.58) globally and 0.7, 95% CI (0.47, 0.99) DALYs per 100,000, in Ethiopia. IHME estimated high SDI countries to have 0.0085, 95% CI (0.0054, 0.013), DALYs per 100,000 (27).

Leprosy Transmission

The precise route of leprosy transmission remains unknown, but nasal secretions of infected individuals' remains the most likely suspect of primary transmission. Person-to-person, through nasal secretions, and zoonotic transmission routes are well supported; however, recent studies suggest that direct inoculation, environmental, and insect related routes may be important transmission factors as well(29).Bratschi et al's 2015 systematic review found that close contacts, particularly those living in the same household as a known leprosy case, is the single most important risk factor or acquisition of leprosy infection (29). However, other than lepromatous leprosy cases, the predominant amount of leprosy

cases are non-infectious while mycobacterium is intracellular. Untreated lepromatous leprosy case patients expel *M. leprae* from nasal and skin secretions (30,31).

Several studies have found potentially viable *M. leprae* in environmental samples including soil and water (32–35). However, these studies have been based on PCR analysis of soil due to the inability to grow M. leprae in vitro, therefore, they cannot determine if the environmental *M. leprae* is viable and capable of infecting humans. This indicates that further research on the viability of leprosy in the environment, especially in soil and water, warrants further research.

WASH

WASH improvements are a known intervention strategy to combat NTDs, particularly soil-transmitted helminths, schistosomiasis, trachoma, and lymphatic filariasis, which have known links to inadequate WASH conditions. WASH factors are inherently related to NTDs, but despite several studies that have detected potentially viable *M. leprae* in water samples and established that leprosy infection is more likely in people who use contaminated water sources, leprosy is largely ignored as a water associated infection (33,35,36). Even the most recent WHO leprosy elimination plan, the 2016-2020 Global Leprosy Strategy, fails to mention water quantity and access as a tool for managing and preventing disease (26).

Immunology and Co-Infections

M. leprae is associated with a complex immune response that differs based on leprosy type: multibacillary (MB) and paucibacillary (PB). These leprosy types are classified by the number of lesions on the skin as well as the results of clinical exams and laboratory tests, including skin smear tests (20). PB leprosy is accompanied by a strong Th1 immune response. However, MB leprosy is associated with a weaker Th1 immune response accompanied by up-regulated Th2 mediated cytokines and inflammatory markers. MB leprosy is believed to be the infectious variety of leprosy, while PB is considered to be the non-infectious variety (37).

Helminth infections typically up-regulate the Th2 immune response and down-regulate the Th1 immune response, meaning the diminished Th1 response may lend to lesser likelihood of the immune system effectively controlling *M. leprae* infection, and therefore, a higher likelihood of MB leprosy (38) . Furthermore, a recent study has shown an association of active overlapping schistosomiasis and leprosy in a co-endemic area of Brazil (39).

Chapter II: Manuscript

Abstract

Access to safe water, sanitation, and hygiene (WASH) is critical for preventing the spread of many neglected tropical diseases (NTDs). While leprosy is thought to be transmitted primarily through nasal secretions from infected individuals, WASH-related transmission factors remain largely unexplored as part of the leprosy transmission cycle. The aim of this project is to better understand WASH exposures among leprosy cases through a case-control study in the North Gondar district of Ethiopia, an area endemic to leprosy and other NTDs. We hypothesize that leprosy cases are more likely to have inadequate access to safe WASH and are more likely to have concurrent schistosomiasis, as schistosomiasis immune consequences may facilitate leprosy infection. Adult leprosy cases and controls without leprosy were recruited from health districts in the North Gondar region and tested for *Schistosoma mansoni* with a point-of-care test. All participants answered a demographic and WASH survey. Participants were assigned a WASH index score using WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) core questions on WASH for household surveys. Eighty-one persons were enrolled with a median age of 33, of whom 75% were male. The majority of the 40 cases had multibacillary disease (83%) and *S. mansoni* infection was detected in 26% of participants. WASH factors associated with leprosy on adjusted analyses showed an association with open defecation (OR=19.9, 95% CI 2.2, 176.3) and lack of access to soap (OR=7.3, 95% CI (1.1, 49.9); but were inconclusive for improved water source (OR=3.5, 95% CI 0.31, 38.8), lack of water treatment (OR=0.28, 95% CI 0.04, 1.8), time to fetch water (OR=0.99, 95% CI 0.93, 1.1), and lack of handwashing (OR=2.5, 95% CI 0.47, 12.8). In the stratified analysis, those with leprosy had a 3.6, 95% CI (0.8, 15.9), greater odds of schistosomiasis in districts bordering the lake, while those with leprosy had 0.33 lower odds of schistosomiasis in districts not bordering the lake 95% CI (0.09, 1.2). Overall, these results suggest that leprosy transmission may be related to WASH adequacy and access as well as schistosomiasis co-infection.

Introduction

Neglected tropical diseases (NTDs) infect over two billion of the world's poorest people, and disproportionately burden low- and middle-income countries (LMIC), which have poor water, sanitation, and hygiene (WASH). Treatment and control of NTDs is included in Goal 3 of the United Nation's Sustainable Development Goals (10).

Leprosy, commonly known as Hansen's disease, is a chronic infectious disease caused by *Mycobacterium leprae*, and is classified as an NTD. An active leprosy infection causes deforming skin lesions and permanent peripheral neuropathy and physical deformity if it is not treated early. Despite multidrug therapy (MDT) and recent public health interventions, close to 200,000 new leprosy cases are reported yearly with 14 LMICs reporting over 94% of all new disease (37).

The World Health Organization (WHO) defines a leprosy case as a person experiencing one or more of the following symptoms: hypopigmented or reddish skin lesions with a loss of sensation; damage to peripheral nerves determined by a loss of sensation or mobility in the hands, feet, or pace; or a positive skin smear. Lab tests including serologic lateral flow assays, PCR-based assays, and enzyme-linked immunosorbent assays can support a clinical diagnosis, but are not very sensitive. And pathologic diagnosis, the mainstay in resource rich areas, is often unavailable in resource poor settings (22)

M. leprae is associated with a complex immune response that differs based on type of leprosy, multibacillary (MB) and paucibacillary (PB). MB versus PB leprosy

case types are classified by the number of lesions and results of skin smear tests (20). MB leprosy is associated with a weakened Th1 immune response and an up-regulation of Th2 mediated cytokines and inflammatory markers. PB leprosy is accompanied by a strong Th1 immune response. MB leprosy is thought to be the infectious leprosy type while PB is considered to be a non-infectious variety (37).

The same causative agent, *M. leprae*, causes PB and MB leprosy types but the type of leprosy a person develops appears to be dependent on the individual's immune system's response to the bacteria. Innate immune genetic variability in toll-like receptor polymorphisms is thought to be a factor related to the leprosy type a person exhibits. Indeed, recent studies estimate that close to 95% of the world's population is not susceptible to leprosy infection (40). Leprosy is thought to be transmitted primarily through nasal secretions or skin lesions of infected individuals; however, recent evidence suggests that zoonotic reservoirs, trauma-related skin-to-skin transmission, and environmental reservoirs may exist.

Schistosomiasis is another NTD caused primarily by three *Schistosoma* species, *Schistosoma mansoni, S. haematobium,* and *S. japonicum.* Schistosoma are transmitted through cercariae, which enter through the skin when a human comes into contact with water contaminated by human waste (12).

Recent studies have suggested that soil-transmitted helminth infection may facilitate leprosy infection (38). Helminth infections typically up-regulate the Th2 immune response and down-regulate the Th1 immune response, meaning the diminished Th1 response may lend to a lesser likelihood of controlling M. leprae

infection, and therefore a higher likelihood of MB leprosy (41). An association of active overlapping schistosomiasis and leprosy was found in a co-endemic area of Brazil (39). In Ethiopia, schistosomiasis infections affect close to five million persons and close to 4000 new leprosy cases are diagnosed each year (28). Due to overlapping endemicity, this makes Ethiopia a good candidate to further study associations between the two infections.

Environmental factors and exposure through poor WASH conditions are associated with several NTDs including schistosomiasis, trachoma, and soil-transmitted helminths (42). Despite several studies that have detected potentially viable *M. leprae* in water samples and established that leprosy infection is more likely for people who have leprosy contaminated water sources, leprosy is largely ignored as a water associated infection (33,35,36). Even the recent WHO 2016-2020 Global Leprosy Strategy fails to mention water quantity and access as a tool for managing or preventing disease (26).

This study investigated the association of WASH factors with leprosy infection through an unmatched case control and further explored schistosomiasis-leprosy co-infections in the Amhara Region of Ethiopia. We hypothesized that poor WASH factors will be associated with a higher odds of leprosy infection and that there would be a higher odds of having leprosy among subjects with schistosomiasis.

Methods

Study Population

A case-control study was conducted in May – October 2018 in the North Gondar, South Gondar, and Gondar Zuria Zones of the Amhara Region of Ethiopia, an area of 171,000 square kilometers, with a population of approximately 17 million people with endemic schistosomiasis and leprosy (43).

Leprosy cases were identified from local leprosy registries and recruited at associated dermatology and family health clinics. Cases were defined as adults 18 and older with a clinical leprosy diagnosis presenting to Gondar area health district offices. Cases were limited to leprosy patients who were currently undergoing treatment or recently diagnosed within the last year. Pregnant women, unconfirmed cases, and those who had finished treatment were excluded as cases. Controls without leprosy were selected from patients present at health offices without suspected leprosy, without previous leprosy infection, and who did not have close contact with a suspected or confirmed leprosy case. Exclusion criteria included children under the age of 18 and pregnant women.

Disability grade, leprosy type, diagnosis date, and treatment medications were recorded for each case. Mid-upper-arm-circumference (MUAC) in centimeters, height in centimeters, and weight in kilograms were measured for all study subjects.

WASH Survey

A WASH survey with questions adapted from WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) core questions on water, sanitation and hygiene for household surveys (44) (Appendix A) was administered to cases and controls to assess household WASH factors including: water source (improved or unimproved), premise access to water, water treatment, time to fetch water, access to soap, handwashing practices, sanitation facility use. The questions also included relevant sociodemographic information such as age, gender, and education status.

Schistosomiasis Testing

Schistosomiasis testing was done on all subjects using Schisto POC-CCA™ rapid test (Schisto POC-CCA cassette based test; Rapid Medical Diagnostics, Pretoria, South Africa). These tests detect active *S. mansoni* infections in urine specimens. The sensitivity for the rapid test is 100% in intensities higher than 400 eggs per gram of feces and 70% in lower burden positive cases. The lowest detectable positive is with a worm burden of approximately 50 worms (45).

We performed the rapid test by collecting urine samples from participants and dropping 100 microliters of urine in the well on the cassette. Results were read after 20 minutes. Invalid tests were repeated.

WASH Index

A composite WASH index was created using the JMP service ladders. Scores were determined by classifying study participants level of service based on their answers to corresponding questions, as identified by the JMP core questions on water, sanitation and hygiene for household surveys (44). The index was scored on a scale of 0-5 for sanitation and drinking water and 0-3 for hygiene (Appendix B) (46).

Statistical Analysis

Data collected from the questionnaires was entered into SAS v. 9.4. Descriptive statistics were tabulated using frequencies, means, median, and standard deviations from proc freq and proc univariate functions in SAS. Unadjusted odds ratio estimates were calculated using proc logistic. A logistic regression model was fit using WASH exposure factors including water source (improved or unimproved), premise access to water, water treatment, time to fetch water, access to soap, handwashing practices, sanitation facility use, and all potential confounders including sex, age, and education status. Sex and age have a known association with leprosy, typically with more leprosy found in men (40,47). Education was included as a marker of socioeconomic status (SES) as some studies have shown an association with leprosy and poor SES (29,47). Education was dichotomized as less than primary education and at least a primary education based on previous studies (47). Stratified odds ratio estimates for leprosy-schistosomiasis co-infections were calculated after stratifying by proximity to Lake Tana. *Woredas*

bordering Lake Tana were classified as close and *woreda* not bordering Lake Tana as far.

Human Subject and Ethical Considerations

Study participation was voluntary, without incentives or compensation to study participants. Potential risk involved in study participation was minimal and limited primarily to a possible breach of confidentiality regarding leprosy status. Patient demographic information did not contain any personal identifiers and data was kept on a password protected computer. The study was approved by the Emory University (00103244) and University of Gondar (O/V/P/RCS/05/1467/2018) Institutional Review Boards and a verbal consent form used on participants. The verbal consent form and survey were approved by the IRBs, translated into Amharic, the local language, and administered by clinical staff from University of Gondar to study participants.

Results

Information was obtained from 40 cases and 41 controls. Leprosy cases were predominantly male with mostly MB disease and poor-moderate WASH access (Table 1). JMP service level scores for drinking water, sanitation, and hygiene are found in Table 2. Only one participant scored at the fifth level of the sanitation ladder with 33 at the second-tier and 20 at the first-tier. This indicates that 53 (65%) participants use an unimproved sanitation source. Sanitation is a three-level ladder with 36 (44%) participants scoring at the top of the ladder with access to soap and water. This does not differentiate between types of handwashing facilities. 64 (79%) participants have access to improved drinking water facilities, and 20 of these are premise access points.

In univariate analysis (Table 3), improved water source, premise water access, lack of soap, lack of handwashing, and open defecation were associated with leprosy. Lack of water treatment, time to fetch water, schistosomiasis, and distance to the lake were not conclusively associated with leprosy infection. In adjusted analysis, open defecation and lack of access to soap were associated with leprosy. Water source and lack of handwashing had point estimates suggestive of an association with leprosy infection. Lack of water treatment and time to fetch water were not associated with leprosy infeciton.

Odds ratio estimates based on relation to Lake Tana are included in Table 6. Those with leprosy had greater odds of schistosomiasis in districts bordering Lake

Tana, while those with leprosy had lower odds of schistosomiasis in districts not bordering the lake.

Discussion

Despite effective multidrug therapy and recent public health interventions, 14 LMICs report over 94% of the nearly 200,000 new leprosy cases every year (37). While the transmission of new cases is thought to occur primarily through nasal secretions of infected individuals, recent evidence suggests that other transmission routes and factors should be considered such as environmental reservoirs (29). This project explored the previously unstudied associations of WASH factors to leprosy infection and identifies the need for further study of these associations including the relationship between schistosomiasis and leprosy.

We hypothesized that WASH factors would be related to leprosy transmission based on previous studies, which suggest transmission factors beyond person-to-person (29). Overall WASH index scores were low for participants, particularly on the sanitation and hygiene ladders. Our study found an association between several WASH factors including soap access and open defecation with leprosy infection, and supports the need for further research into these associations. We also hypothesized that there would be an association of schistosomiasis and leprosy due to previous studies linking helminth infection to leprosy infections and the immune response to helminth infections (39,41). Helminth infections up-regulate the Th2 immune response and down-regulate the Th1 response, which reduces the immune system's ability to control *M. leprae* infection. However, overall, schistosomiasis infection was not found to be significantly related to leprosy infection, although a larger study may have detected a difference given the results of

the stratified analysis which suggested that schistosomiasis may have been associated with leprosy in regions nearer to the lake..

WASH index scores in general were low for the entire study population; however, the number of leprosy cases was particularly low on several. While most leprosy cases had access to an improved water source, only 20% had water access in their home or yard. In sanitation, more than one-third did not have access to any facility and none had access to an improved facility not shared with other households. Finally, half of leprosy cases did not have access to soap and water for handwashing. Considering that the univariate analysis, water source, premise access, lack of soap, lack of handwashing, and open defecation appear to be related to leprosy, adjusted analysis further supports an association of open defecation and lack of soap with leprosy.

Considering the slow replication of *M. leprae,* this association with WASH factors and leprosy seems plausible, as handwashing and bathing could provide an opportunity to wash the bacteria off the skin prior to infection (48). Proper hygiene including bathing and handwashing is already known to reduce severity and disability of leprosy infection, and may be able to do this by washing away leprosy bacteria on the skin (49). Having access to water in or very near the house allows for more regular bathing and handwashing, which could reduce the chance for leprosy infection and reduce disability for infected individuals.

Recent studies have suggested environmental reservoirs of leprosy may exist, as global transmission of leprosy has not diminished despite effective MDT

(50,51). Water that is shared or reused from a source patient may be environmental reservoirs for infection, possibly by aerosolization of *M. leprae.* Contaminated water may be capable of transmitting viable *M. leprae,* as recent studies have found potentially viable bacteria in water and in amoebas commonly found in untreated water (50,51). The viability of leprosy bacteria found in the environment is difficult to prove, however, as *M. leprae* does not grow in laboratory conditions (52). Studies on environmental reservoirs of leprosy have relied primarily on rt-PCR of leprosy to assess reliability, and one study quantifying mRNA from *M. leprae* lends stronger support to the ability of these studies to assess viable bacteria in environmental samples (29,35,36,47,53).

While studies have linked water to possible routes of infection, sanitation has not been implicated as a potential transmission route of leprosy (29). Potentially viable *M. leprae* has been found in soil samples, but the route of transfer from person to environment is not understood (35). This is likely from shedding from the skin rather than stool, as viable *M. leprae* is not known to be excreted in stool (35). Open defecation was associated with leprosy in this study, and we believe that open defecation is significant because it accounts for other factors including socio-economic status and potentially soil-transmitted helminth infections as open defecation has a known association with soil-transmitted helminth infection (54).

While our unadjusted estimates suggest a protective association of schistosomiasis on leprosy infection, region specific schistosomiasis infection points towards an association between schistosomiasis and leprosy within the Lake Tana

area. While proximity to a body of water should be considered as a WASH factor and as an important contributor to schistosomiasis infection, we do not know if there is a true difference in schistosomiasis-leprosy co-infections between communities near a body of water and far from a body of water since our study was not designed to detect a difference in schistosomiasis status by proximity to the lake.

Due to the similarity in WASH access to other populations in developing countries, the associations found in this project are likely generalizable to populations with a large number of residents living in poverty and communities with endemic leprosy and schistosomiasis. The findings point towards a general association between WASH and leprosy and while not necessarily significant in all findings, point towards the need for further research on water as a transmission route and associations with WASH factors and leprosy.

Our study faced several key limitations including a small sample size, which limited the model reliability and the overall statistical analysis of the project. A further weakness of our study was the presence of unquantified confounders such as economic status of participants. Education was used to account for this factor in our study, but a more direct measure of SES could lead to better estimates. Other missing key confounders include soil-transmitted helminth infection and household and social leprosy contacts.

While this study does not prove a causal relationship between WASH factors and leprosy, it does elucidate the need for further study and analysis of these relationships between WASH and leprosy. Future studies should further consider

WASH factors presented in this study and soil-transmitted helminth infections, water quantity, water quality, bathing frequency, water-reuse behaviors, and poverty-related factors as risks for leprosy.

References

1. World Health Organization. Neglected Tropical Diseases. *WHO*. 2018;(http://www.who.int/neglected_diseases/diseases/en/)

2. WHO | General publications. *WHO*. (http://www.who.int/neglected_diseases/resources/general_publications/en/). (Accessed February 3, 2019)

3. Accelerating work to overcome the global impact of neglected tropical diseases : a roadmap for implementation : executive summary. (https://apps.who.int/iris/handle/10665/70809). (Accessed January 30, 2019)

4. Molyneux DH, Malecela MN. Neglected Tropical Diseases and the Millennium Development Goals-why the "other diseases" matter: reality versus rhetoric. *Parasit. Vectors*. 2011;4(1):234.

5. United Nations Millennium Development Goals. (http://www.un.org/millenniumgoals/). (Accessed January 31, 2019)

6. Smith J, Taylor EM. MDGs and NTDs: Reshaping the Global Health Agenda. *PLoS Negl. Trop. Dis.* [electronic article]. 2013;7(12). (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3861184/). (Accessed January 31, 2019)

7. Christopher Fitzpatrick, Dirk Engels. Leaving no one behind: a neglected tropical disease indicator and tracers for the Sustainable Development Goals: Box 1. *ResearchGate*. (https://www.researchgate.net/publication/297595275_Leaving_no_one_behind_a_neglected_tropical_disease_indicator_and_tracers_for_the_Sustainable_Development_Goals_Box_1). (Accessed January 31, 2019)

8. Goal 3 .:. Sustainable Development Knowledge Platform. *Sustain. Deveopment Goal 3*. (https://sustainabledevelopment.un.org/sdg3). (Accessed January 31, 2019)

9. Goal 6 .:. Sustainable Development Knowledge Platform. (https://sustainabledevelopment.un.org/sdg6). (Accessed January 31, 2019)

10. WHO | NTD and SDG. *WHO*. 2017;(http://www.who.int/neglected_diseases/global-partners-meeting/NTD-and-SDG/en/). (Accessed January 31, 2019)

11. World Health Organization Regional Office for Africa. 2016 Annual Report Communicable Diseases Cluster. 2017;(https://afro.who.int/sites/default/files/2017-11/WHO%20AFRO%20CDS%20Annual%20Report%202016%20web%20version_1.pdf). (Accessed January 31, 2019)

12. CDC - Schistosomiasis. 2018;(https://www.cdc.gov/parasites/schistosomiasis/index.html). (Accessed January 31, 2019)

13. Schistosomiasis. (https://www.who.int/news-room/fact-sheets/detail/schistosomiasis). (Accessed February 3, 2019)

14. CDC - DPDx - Schistosomiasis Infection. 2017;(https://www.cdc.gov/dpdx/schistosomiasis/index.html). (Accessed February 3, 2019)

15. CDC - Schistosomiasis - Biology. 2017;(https://www.cdc.gov/parasites/schistosomiasis/biology.html). (Accessed May 17, 2018)

16. CDC - Schistosomiasis - Epidemiology & Risk Factors. 2018;(https://www.cdc.gov/parasites/schistosomiasis/epi.html). (Accessed February 3, 2019)

17. Katz N, Chaves A, Pellegrino J. A simple device for quantitative stool thick-smear technique in Schistomiasis Mansoni. 1971 397 p.

18. Stothard JR, Kabatereine NB, Tukahebwa EM, et al. Use of circulating cathodic antigen (CCA) dipsticks for detection of intestinal and urinary schistosomiasis. *Acta Trop.* 2006;97(2):219–228.

19. Leprosy. (https://www.who.int/news-room/fact-sheets/detail/leprosy). (Accessed January 16, 2019)

20. WHO | Elimination of leprosy FAQ. *WHO*. (http://www.who.int/lep/strategy/faqs/en/). (Accessed January 17, 2019)

21. WHO | WHO to publish first official guidelines on leprosy diagnosis, treatment and prevention. (https://www.who.int/neglected_diseases/news/WHO-to-publish-first-guidelines-on-leprosy-diagnosis/en/). (Accessed April 10, 2019)

22. WHO | Leprosy: improved reporting, active case-finding and enhanced data collection reveal hidden cases. *WHO*. (http://www.who.int/neglected_diseases/news/Leprosy_improved_reporting/en/). (Accessed February 3, 2019)

23. WHO | WHO to publish first official guidelines on leprosy diagnosis, treatment and prevention. *WHO*. (http://www.who.int/neglected_diseases/news/WHO-to-publish-first-guidelines-on-leprosy-diagnosis/en/). (Accessed January 20, 2019)

24. Gillini L, Cooreman E, Wood T, et al. Global practices in regard to implementation of preventive measures for leprosy. *PLoS Negl. Trop. Dis.* 2017;11(5):e0005399.

25. World Health Assembly. Resolution WHA 51.15 : "Elimination of Leprosy as a Public Health Problem". 1998;

26. Global Leprosy Strategy 2016-2020: Accelerating towards a leprosy-free world. (https://apps.who.int/iris/handle/10665/208824). (Accessed January 28, 2019)

27. GBD Compare | IHME Viz Hub. (http://vizhub.healthdata.org/gbd-compare). (Accessed January 16, 2019)

28. GHO | By country | Ethiopia - statistics summary (2002 - present). *WHO*. (http://apps.who.int/gho/data/node.country.country-ETH). (Accessed January 18, 2019)

29. Bratschi MW, Steinmann P, Wickenden A, et al. Current knowledge on Mycobacterium leprae transmission: a systematic literature review. *Lepr. Rev.* 2015;86(2):142–155.

30. Rodrigues LC, Lockwood DN. Leprosy now: epidemiology, progress, challenges, and research gaps. *Lancet Infect. Dis.* 2011;11(6):464–470.

31. Job CK, Jayakumar J, Kearney M, et al. Transmission of leprosy: a study of skin and nasal secretions of household contacts of leprosy patients using PCR. *Am. J. Trop. Med. Hyg.* 2008;78(3):518–521.

32. Wahyuni R, Adriaty D, Iswahyudi I, et al. Mycobacterium leprae in Daily Water Resources of Inhabitants Who Live in Leprosy Endemic Area of East Java. *Indones. J. Trop. Infect. Dis.* 2010;1(2):65–68.

33. Matsuoka M, Izumi S, Budiawan T, et al. Mycobacterium leprae DNA in daily using water as a possible source of leprosy infection. *Indian J. Lepr.* 1999;71(1):61–67.

34. Lavania M, Katoch K, Katoch VM, et al. Detection of viable Mycobacterium leprae in soil samples: Insights into possible sources of transmission of leprosy. *Infect. Genet. Evol.* 2008;8(5):627–631.

35. Turankar RP, Lavania M, Singh M, et al. Dynamics of Mycobacterium leprae transmission in environmental context: Deciphering the role of environment as a potential reservoir. *Infect. Genet. Evol.* 2012;12(1):121–126.

36. FAUTH. Viability of *Mycobacterium leprae* in the environment and its role in leprosy dissemination. 1990;(http://www.ijdvl.com/printarticle.asp?issn=0378-6323;year=2016;volume=82;issue=1;spage=23;epage=27;aulast=Mohanty). (Accessed January 15, 2019)

37. White C, Franco-Paredes C. Leprosy in the 21st Century. *Clin. Microbiol. Rev.* 2015;28(1):80–94.

38. Diniz LM, Magalhães EFL, Pereira FEL, et al. Presence of intestinal helminths decreases T helper type 1 responses in tuberculoid leprosy patients and may increase the risk for multi-bacillary leprosy. *Clin. Exp. Immunol.* 2010;161(1):142–150.

39. Diniz LM, Zandonade E, Dietze R, et al. Short report: do intestinal nematodes increase the risk for multibacillary leprosy? *Am. J. Trop. Med. Hyg.* 2001;65(6):852–854.

40. Polycarpou A, Walker SL, Lockwood DN. New findings in the pathogenesis of leprosy and implications for the management of leprosy. *Curr. Opin. Infect. Dis.* 2013;26(5):413–419.

41. Phillips DA, Ferreira JA, Ansah D, et al. A tale of two neglected tropical infections: using GIS to assess the spatial and temporal overlap of schistosomiasis and leprosy in a region of Minas Gerais, Brazil. *Mem. Inst. Oswaldo Cruz*. 2017;112(4):275–280.

42. WHO | Water sanitation and hygiene for accelerating and sustaining progress on neglected tropical diseases. *WHO*. (http://www.who.int/water_sanitation_health/publications/wash-and-ntd-strategy/en/). (Accessed March 18, 2019)

43. Census 2007. (http://www.csa.gov.et/census-report/complete-report/census-2007?start=5). (Accessed February 28, 2019)

44. Core questions | JMP. (https://washdata.org/monitoring/methods/core-questions). (Accessed April 17, 2019)

45. Rapid Medical Diagnostics. Schisto POC-CCA Rapid Test for Qualitative Detection of: Bilharzia (Schistosomiasis). (http://www.rapid-diagnostics.com/downloads/RMD%20Pamphlet%202011_06_13%20.pdf). (Accessed April 11, 2019)

46. World Health Organization, WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, Unicef. WASH in the 2030 Agenda: New Global Indicators for Drinking Water, and Sanitation. (https://data.unicef.org/wp-content/uploads/2017/07/JMP-2017-wash-in-the-2030-agenda.pdf). (Accessed April 11, 2019)

47. Kerr-Pontes LRS, Barreto ML, Evangelista CMN, et al. Socioeconomic, environmental, and behavioural risk factors for leprosy in North-east Brazil: results of a case-control study. *Int. J. Epidemiol.* 2006;35(4):994–1000.

48. Bhat RM, Prakash C. Leprosy: An Overview of Pathophysiology. *Interdiscip. Perspect. Infect. Dis.* [electronic article]. 2012;2012. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3440852/). (Accessed April 20, 2019)

49. Catherine Garsed, Robyn Waite. The importance of water, sanitation and hygiene for lymphatic filariasis and leprosy care and inclusion. 2015;(https://www.leprosymission.org.uk/documents/WASH_in_LF_and_leprosy_self-care_briefing_note_2.pdf). (Accessed April 9, 2019)

50. Wheat WH, Casali AL, Thomas V, et al. Long-term Survival and Virulence of Mycobacterium leprae in Amoebal Cysts. *PLoS Negl. Trop. Dis.* [electronic article]. 2014;8(12). (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4270725/). (Accessed April 20, 2019)

51. Lahiri R, Krahenbuhl JL. The role of free-living pathogenic amoeba in the transmission of leprosy: a proof of principle. *Lepr. Rev.* 2008;79(4):401–409.

52. Davis GL, Ray NA, Lahiri R, et al. Molecular Assays for Determining Mycobacterium leprae Viability in Tissues of Experimentally Infected Mice. *PLoS Negl. Trop. Dis.* [electronic article]. 2013;7(8). (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3750008/). (Accessed April 20, 2019)

53. Arraes MLB de M, de Holanda MV, Lima LNGC, et al. Natural environmental water sources in endemic regions of northeastern Brazil are potential reservoirs of viable Mycobacterium leprae. *Mem. Inst. Oswaldo Cruz*. 2017;112(12):805–811.

54. Ganguly S, Barkataki S, Karmakar S, et al. High prevalence of soil-transmitted helminth infections among primary school children, Uttar Pradesh, India, 2015. *Infect. Dis. Poverty* [electronic article]. 2017;6. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5632835/). (Accessed April 20, 2019)

Table 2. WASH Index Scores[a]

Tables

Table 1. Demographic and Clinical Variables

Variable	Total (n=81)
Age, years (median, SD)	33(18.4
Sex, n (%)	
Male	61(75.3)
Leprosy Type, n (%)	
Total Leprosy Cases	40
MB	33(82.5)
PB	4(10)
Unknown	3(7.5)
Disability Grade at Diagnosis	
Total Leprosy Cases	40
Grade 0	20(50)
Grade 1	12(30)
Grade 2	8(5)
Positive Schistosomiasis, n (%)	21(25.9)
Drinking Water Source, n (%)	
Piped Water to House/Yard	25(30.9)
Public Tap/Standpipe	29(35.8)
Other Protected Source	14(17.3)
Unprotected Spring	10(12.4)
Surface Water	3(3.7)
Water fetching time (median, SD)	10(15.4)
Toilet Facility, n (%)	
Flush Toilet	5(6.2)
Improved Pit Latrine	23(28.8)
Pit Latrine	32(39.5)
No Toilet Facility	20(24.7)
Household Water Treatment, n (%)	
Yes	21(25.9)
No	60(74)
Soap Available for Handwashing, n (%)	
Yes	44(54.3)
No	36(44.4)
Handwashing at home, n (%)	
No handwashing	29(35.8)
In kitchen	14(17.3)
By latrine/toilet	6(7.4)

Drinking Water	Total N (%)	Leprosy cases, N (%)	Sanitation	Total N, (%)	Leprosy cases, N (%)	Hygiene[b]	Total N, (%)	Leprosy cases, N (%)
Drinking water from an improved water source, which is located on premises, available when needed and free from faecal and priority chemical contamination.	24(30)	8(20)	Use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site.	1(1)	0(0)			
Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing.	40(49)	22(55)	Use of improved facilities, which are not shared with other households.	14(17)	11(28)	Availability of a handwashing facility on premises with soap and water.	36(44)	11(28)
Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing.	3(4)	0(0)	Use of improved facilities shared between two or more households.	13(16)	3(8)	Availability of a handwashing facility on premises without soap and water.	16(20)	8(20)
Drinking water from an unprotected dug well or unprotected spring.	10(12)	9(23)	Use of pit latrines without a slab or platform, hanging latrines or bucket latrines.	33(41)	11(28)	No handwashing facility on premises.	29(36)	20(50)
Drinking water directly from a river, dam, lake pond, stream, canal or irrigation canal.	4(5)	1(3)	Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches, and other open spaces or with solid waste.	20(25)	15(38)			

[a]Score ladder taken from JMP service ladders found in Appendix B

[b]Hygiene is a three level ladder while drinking water and sanitation are five level

Table 3. Unadjusted and Adjusted WASH Factor Associations

Covariate	OR	Lower Limit[a]	Upper Limit	aOR[f]	Lower Limit[a]	Upper Limit
Water Source[b]	4.22	1.07	16.72	3.47	0.31	38.76
Premise Access[c,d]	2.83	1.05	7.65	-	-	-
Lack of Water Treatment	1.62	0.59	4.40	0.28	0.04	1.79
Time to get water	1.01	0.98	1.04	0.99	0.93	1.05
Lack of Soap	2.61	1.06	6.42	7.31	1.07	49.94
Lack of Handwashing	4.56	1.69	12.28	2.46	0.47	12.82
Open Defecation	4.32	1.67	11.18	19.86	2.24	176.25
Schistosomiasis[d]	0.54	0.20	1.49	-	-	-
Lake Region[d,e]	0.60	0.22	1.69	-	-	-

[a]95% confdence limits
[b]Unimproved vs. Improved
[c]In-home or in-yard water access
[d]Not included in adjusted model
[e]Region bordering Lake Tana. Not included in adjusted model
[f]Model adjusted for age, sex, and education

Table 4. Leprosy-Schistosomiasis Co-infection Stratified by Proximity to Lake Tana

Strata	OR	Lower Limit[a]	Upper Limit[a]
Near Lake Tana	3.56	0.80	15.85
Distant from Lake Tana	0.33	0.09	1.19

[a]95% confidence limits

Chapter III: Summary, Public Health Implications, and Possible Future Directions

Overall, this project assessed the association between WASH factors and leprosy infection with special consideration for leprosy-schistosomiasis co-infections. We hypothesized that we would find an association between WASH factors and leprosy and that there would be a higher likelihood of leprosy infection among participants with active schistosomiasis infection. Our study found that WASH factors including water source, premise access, access to soap, handwashing practices, and open defection are related to leprosy infection. Schistosomiasis infection, however, was not found to be associated with leprosy infection.

Future studies should further consider these WASH factors as well as the possibility of *M. leprae* infection related to stool, poverty, soil-transmitted helminth infection, water treatment, water quantity, and water quality. Identifying ways to assess viability or to culture *M. leprae* in laboratory conditions could further strengthen the findings of related studies and improve the ability to research transmission routes.

It is our hope that this project informs strategies to improve leprosy elimination strategies in the future, particularly by considering WASH factors as a tool for quelling transmission. Water is not mentioned in WHO's most recent leprosy plan, the Global Leprosy Strategy 2016-2020, which is odd considering the preestablished role of water in leprosy disease management. We hope that this study can not only inform future projects, but also remind those working to control

leprosy of the importance of adequate WASH access in preventing the spread of disease.

Appendix A

Water, Sanitation, and Hygiene Practices (WASH) and the Risk of Soil-Transmitted Helminth (STH) Infection, Schistosomiasis, and Leprosy

Rollins School of Public Health, Emory University, 2018

Hi my name is _____. Thank you for participating in this survey. We are part of a team from Emory University and are interested in reducing the number of infections in your home and community. Your answers will provide valuable knowledge that will help protect your home and community. You have signed a consent form and everything you say will be kept private and anonymous. Your participation is completely voluntary, and you are allowed to change your mind at any point in time. However, we appreciate your contribution. This survey should take approximately 20 minutes. Do you still agree to participate?

Yes No

Part. A. Demographic and Household Information

Question:	Response:
A1. How old were you, in years, on your last birthday?	_____ Refused……..98 Didn't Answer……..99
A2. What is your gender?	Male……1 Female…….2

	Refused……98 Didn't Answer…….99
A3. How many people live in your home?	[___ ___] Refused……..98 Don't know……99
A4. Does any member in this household own[1] A6a. A watch? A6b. A bicycle? A6c. A motorcycle or motor scooter? A6d. An animal-drawn cart? A6e. A car or truck? A6f. A boat with motor? A6g. A mobile phone? A6h. A radio?	Yes No a. Watch……..1 2 b. Bicycle……..1 2 c. Motorcycle / scooter……..1 2 d. Animal-drawn cart ……..1 2 e. Car or truck…….1 2 f. Boat with motor..1 2 g. A mobile phone ..1 2 h. A radio……..1 2
A5. Does any member of this household own agricultural land?[1]	a. Yes……1 b. No……..2 c. Refused……98 d. Don't know……99
A6. Does any member of this household own any livestock, herds, other farm animals, or poultry?[1]	a. Yes……1 b. No……..2 c. Refused……98

	d. Don't know……..99
A7. Does any member of this household have a bank account?[1]	a. Yes……1 b. No……..2 c. Refused…… 98 d. Don't know……..99
A8. What grade level did you complete?	a. [___ ___] b. None……..0 c. Refused……..98 d. Don't know……..99

Part B. Household Water and Hygiene

Question:	Response:
B1. What is the MAIN source of drinking water for members of your household?[2] *Please only state one.*	a. Piped water to household……11 b. Piped water to yard……..12 c. Public tap / standpipe……..13 d. Borehole……..14 e. Protected dug well……..15 f. Unprotected dug well……..21 g. Protected spring……..16 h. Unprotected spring……22 i. Rainwater collection……..17 j. Bottled water……..18 k. Cart with small tank / drum..23 l. Tanker-truck……..24 m. Surface water……..25 n. Other……..88 Specify_____ o. Refused……..98 p. Don't know……..99

B2. What is the MAIN source of water used for cooking?[2] *Please only state one.*	a. Piped water to household……11 b. Piped water to yard……12 c. Public tap / standpipe……13 d. Borehole……14 e. Protected dug well……15 f. Unprotected dug well……21 g. Protected spring……16 h. Unprotected spring……22 i. Rainwater collection……17 j. Bottled water……18 k. Cart with small tank / drum..23 l. Tanker-truck……24 m. Surface water……25 n. Other……88 Specify_____ o. Refused……98 p. Don't know……99
B3. What is the MAIN source of water used for bathing and hand washing?[2] *Please only state one.*	a. Piped water to household……11 b. Piped water to yard……12 c. Public tap / standpipe……13 d. Borehole……14 e. Protected dug well……15 f. Unprotected dug well……21 g. Protected spring……16 h. Unprotected spring……22 i. Rainwater collection……17 j. Bottled water……18 k. Cart with small tank / drum..23 l. Tanker-truck……24 m. Surface water……25 n. Other……88 Specify_____ o. Refused……98 p. Don't know……99

B4. How long does it take (in minutes) to go to the water source, to get drinking water, and come back?[2]	a. Number of minutes___ ___ ___ b. Refused……98 c. Don't know……99
B5. Who collects the water the most frequently?	a. The interviewee……1 b. Child – age __ __ ……2 c. Spouse……3 d. Other adult in the household..4 e. Other……88 f. Refused……98 g. Don't know……99
B6. Do you treat your water in any way to make it safer to drink?[2]	a. Yes……1 → B7 b. No……2 → B8 c. Refused……98 → B8 d. Don't know……99 → B8
B7. What do you usually do to the water to make it safer to drink?[2] *Please state only one.*	a. Boil……11 b. Add bleach / chlorine……12 c. Strain it through a cloth……21 d. Use a water filter……13 e. Solar disinfection……14 f. Let it stand and settle……22 g. Other……88 Specify_____ h. Refused……98 i. Don't know……99
B8. What type of toilet facility do the members of your household most often use?[2] *Please state only one.*	a. Flush toilet……11 b. Ventilated improved pit latrine……12 c. Pit latrine with slab……13 d. Pit latrine without slab / open pit……21 e. Composting toil……22 f. Bucket……23 g. Hanging toilet……24 h. No facilities or fi ……29 i. Other ……88 Specify_____ j. Refused……98 k. Don't know……99
B9. Do you share this facility with other	a. Yes ……1 → B10 b. No ……2 → B11

households?[2]	c. Refused……98 → B11 d. Don't know……99 →B11
B10. How many households use this facility?[2]	a. [___ ___ ___] b. Refused……98 c. Don't know……99
B11. Do you have any children who are not toilet-trained?	a. Yes……1 → B12 b. No……2 → C1 c. Refused……98 → C1 d. Don't know……99 → C1
B12. The last time your youngest child had a bowel movement, what was done to dispose of the stools?[2]	a. Child used latrine / toilet……1 b. Rinsed / placed into toilet / latrine……2 c. Rinsed / placed into drain or ditch……3 d. Thrown into garbage……4 e. Buried……5 f. Left in the open……6 g. Other……88 Specify_____ h. Refused……98 i. Don't know……99

Part C. Knowledge of Infection Transmission

Question:	Response:
C1. How does one get infected with intestinal worms?	a. Contaminated food……1 b. Contaminated water……2 c. Mosquitos……3 d. Swimming……4 e. Animals……5 f. Personal contact with others…,…6 g. Walking barefoot……7

	h. Other (specify)_____.....88 i. Refused……..98 j. Don't know……99
C2. What can be done to prevent infection with intestinal worms?	a. Treating drinking water……1 b. Washing hands……2 c. Toweling off……3 d. Wearing shoes……4 e. Defecating in a latrine……5 f. Avoid swimming……6 g. Cook food thoroughly……7 h. Take pills……8 i. Other ……88 Specify_____ j. Refused……98 k. Don't know……99
C3. What causes Bilharzia (schistosomiasis)?	a. Contaminated food……1 b. Contaminated water……2 c. Mosquitos……3 d. Swimming in fresh water……4 e. Animals……5 f. Personal contact with other……6 g. Walking barefoot……7 h. Snails……8 i. Other ……88 Specify _____ j. Refused……9 k. Don't know……99
C4. What can be done to prevent infection with schistosomiasis?	a. Treating drinking water……1 b. Washing hands……2 c. Toweling off……3 d. Wearing shoes……4 e. Defecating in a latrine……5 f. Avoid swimming……6 g. Avoid urinating in fresh water…7 h. Other ……88 Specify_____ i. Refused……98 j. Don't know……99
C5. How do you catch leprosy/Hansen's Disease?	a. Drinking "bad" water……1 b. Not washing your hands……2 c. Eating "bad "food……3 d. From the air/inhaling……4 e. From animals……5 f. Touching someone with

	leprosy……..…….6
C6. How do you protect yourself from leprosy/Hansen's Disease?	a. Washing your hands……..…..1 b. Good personal hygiene……..…..2 c. Using soap when bathing……..3 d. Washing your clothes ……..…..4 e. Washing your face……..…..5

Part E. Handwashing

Questions:	Responses:
E1. Where do you wash your hands at home?	a. No handwashing……..…..1 b. In kitchen……..…..2 c. By latrine/toilet……..…..3 d. Other (please specify)_____ e. Refused to answer……..…..4 f. Don't know……..…..5
E2. Do you have soap available today to wash hands at home?	a. Yes……..…..1 b. No……..…..2 c. Refused……..…..98 d. Don't know……..…..99

Thank you for participating in this survey Your time and contribution will increase knowledge to fight infection in your community.

End time __ __: __ __

[1]Questions adapted from the DHS Household Questionnaire, Nov 2011.

[2]Questions adapted from the WHO / Unicef Joint Monitoring Programme (JMP) for Water Supply and Sanitation: Core Questions On Drinking-Water And Sanitation for Household Surveys, 2008

Survey Adapted from Dr. Jessica Fairley's GH502 Spring 2014 Survey

Appendix B


JMP LADDERS
DRINKING WATER
SANITATION
HYGIENE
SAFELY MANAGED
Drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination
Use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site
BASIC
Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing
Use of improved facilities which are not shared with other households
Availability of a handwashing facility on premises with soap and water
LIMITED
Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing
Use of improved facilities shared between two or more households
Availability of a handwashing facility on premises without soap and water
UNIMPROVED
Drinking water from an unprotected dug well or unprotected spring
Use of pit latrines without a slab or platform, hanging latrines or bucket latrines
NO FACILITY
No handwashing facility on premises
SURFACE WATER
Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal
OPEN DEFECATION
Disposal of human faeces in fields, forests, bushes, open bodies of water, beaches and other open spaces or with solid waste
Note: Improved sources include: piped water, boreholes or tubewells, protected dug wells, protected springs and packaged or delivered water
Note: Improved facilities include: flush/pour flush to piped sewer system, septic tanks or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs
Note: Handwashing facilities may be fixed or mobile and include a sink with tap water, buckets with taps, tippy-taps, and jugs or basins designated for handwashing. Soap includes bar soap, liquid soap, powder detergent, and soapy water but does not include ash, soil, sand or other handwashing agents.
Household surveys increasingly include a section on hygiene practices where the surveyor visits the handwashing facility and observes if water and soap are present. Observation of handwashing materials by surveyors represents a more reliable proxy for handwashing behaviour than asking individuals whether they wash their hands. The small number of cases where households refuse to give enumerators permission to observe their facilities are excluded from JMP estimates.
WHO
UNICEF
JMP