A multidimensional measurement of the health impact of community-based water treatment systems in Uganda

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ABSTRACT

Using a unique combination of ethnographic methods, healthcare facility chart reviews, and individual waterborne parasite tests, the health impacts of providing water treatment systems for communities in Uganda are compared to the impact measured using identical water technology and similar research methods in Honduras. While self-reported diarrhea rates improved in the Ugandan test communities when compared to controls, no significant impact was detected in any of the other measures. This contrasts sharply with findings in Honduras where all measures demonstrated statistically significant improvement after installation of identical water treatment systems. Ongoing ethnographic work reveals that knowledge of waterborne pathogens was universal in both Uganda and Honduras while practices related to water consumption varied greatly. Additional factors effecting these outcomes will be discussed.

Key words | diarrhea, health, hygiene, methodology, water, waterborne pathogens

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INTRODUCTION

According to World Health Organization data (WHO 2014), at least 4% of the worldwide burden of disease would be alleviated by improved water supply, sanitation, hygiene, and management of water resources – making water related diseases arguably the most manageable set of health problems affecting modern humans.

A great deal of work has been done attempting to measure the impact of interventions to provide improved water sources at the household level, and less frequently, at the community level. The overwhelming majority of these studies have also used either key informant or self-reporting of diarrhea (defined as three or more loose stools per day) as the measure of disease burden. Reliance upon such non-objective measures introduces a host of potentially confounding variables and yet appears to have been used in all of the 2,120 published studies reviewed in

a far-reaching meta-analysis produced for the World Bank on diarrhea and water interventions (Fewtrell & Colford 2005). While some of these deficiencies may be reduced by shortening recall time to 72 hours or less, it appears that the majority of such assessments have continued to use questionable methods and potentially profound observer effects remain. Estimates of disease load changes are further impeded by some researchers' concentration on known users of water systems rather than measurements on community levels of disease changes regardless of compliance, thus making extrapolations of disease rate changes inappropriate (Brown & Thomas 2012). This is especially true of point-of-use water system studies. A further confounding effect from measuring diarrhea only is that, while the most common waterborne pathogens cause diarrhea, many other non-waterborne pathogens also cause the same

symptom – most notably, viral and food-borne illnesses (Parashar *et al.* 2003).

Under a private grant, Water Missions International (WMI) began construction of community water treatment facilities in 25 communities in Uganda within 1 km of Lake Victoria. The location of the projects was on request of the donor. The water treatment facilities use a series of mixed media filtration followed by disinfection by addition of two parts per million of chlorine. Chlorine levels are further adjusted to provide a residual at the point of distribution of 0.2–0.5 parts per million. This residual assures that chlorine is not totally consumed during the initial decontamination process as well as providing additional protection from household contamination prior to consumption.

WMI requested the impact study discussed in this paper as part of an ongoing quality improvement effort. The specific goal of this research as relates to this paper was to measure the health impact on the communities being served by the community water treatment system.

METHODS

Researchers were provided with a list of communities whose construction plans coincided appropriately with planned research. Communities were then assigned to either the Test or Control groups based upon this schedule. Potential Test Communities were scheduled to receive water treatment systems at the time when or before the initial round of data was gathered. Potential Control Communities were selected from those scheduled to receive treatment facilities after the research had been completed. Three final test and three control communities were selected by pair matching them according to population, presence of a public health facility, and proximity to Lake Victoria.

Geographical cluster sampling was performed using satellite imagery to identify physical housing units and potential households. In order to assure representative sampling from significant geographical features such as the lake access and boreholes, each community was divided into sections of approximately equal numbers of households and assigned to researcher units. These households were given numbers, randomly selected, and then approached

sequentially until the quota for that section had been filled. While some households were skipped because no one was home when approached, no household recruited by the sampling method refused to participate. One interview was performed at each house and the entire household was invited to provide stool samples. In all cases, the interviewee also provided a stool sample. People were excluded if they were younger than 3 or older than 70 years of age, pregnant, or on long-term medication for HIV/AIDS. Global positioning system coordinates as well as photographs of homes and participants were taken to aid the researchers in finding participants during the follow-up phases. Lab personnel were blinded to the interview results.

Incentives to participate were provided in the form of treatment for detected parasites, soap, and printed photographs. The sampling frame for each village was defined as everyone living within a 1 km radius of the most densely populated area.

All interviews were entered into a qualitative analysis software package (Atlas.ti). Using prior ethnographic materials from these interviews as a base of information, a Knowledge, Attitude, and Practice (KAP) survey was developed to include such items as water sources, hand and water container washing practices, diarrhea, sources of knowledge, and economic indicators. All self-reported practices and indices of diarrhea were limited to recall of the past 72 hours.

In order to assess the effect of economic status on the health impact on water and sanitation practices, designed into the KAP survey were indicators, which were used to create an economic scale. Indicators of economic status included home building materials (mud versus brick), roofing materials (corrugated iron or thatch), ownership of a private latrine, as well as ownership of a cell phone, motorbike, car, or boat. Each of these factors was given a value of one or zero for a possible total of seven points – seven representing the highest economic status.

We intended also to measure the penetration of Water Sanitation and Hygiene training into the community at large. Initial ethnographic work revealed a pre-existing high level of knowledge of waterborne illnesses and the need for safe water practices making such measurements problematic. After pilot testing multiple questions, we

included in the final KAP survey a question asking if the subject knew why chlorine was added to water, a subject WMI emphasized in its training but which was not commonly discussed among initial interviewees. KAP survey and parasite tests results were entered into electronic spreadsheets and PASW Statistics 18 for analysis.

Recent advances in highly sensitive and specific rapid immunoassays for waterborne parasite diseases have made field-testing of individual fecal specimens now possible (Garcia *et al.* 2000; Sharp *et al.* 2001). These devices test for species-specific antigens of common parasites known to be primarily waterborne. The device chosen for this study tested for three protozoan parasites: *Giardia lamblia* (now widely known as *Giardia intestinalis*), *Entamoeba histolytica/Entamoeba dispar*, and *Cryptosporidium parvum* antigens. Previous work has shown these tests to have both specificity and sensitivity in excess of 96% for the before-mentioned pathogens (Garcia *et al.* 2000). In this study, immunoassay of stool for these waterborne parasites was used as an indicator that the subject had been exposed to waterborne pathogens and was therefore at risk of these and other infectious waterborne illnesses. All specimens were tested within 12 hours of collection using the Triage Micro Parasite Panel® manufactured by Biosite Incorporated. All subjects at any phase of the study who tested positive for protozoan antigens were treated with an age-adjusted dose of tinidazole. The effect of medical treatment of subjects upon the present study is to provide a population that on follow-up either tested negative or were given highly effective treatment at the beginning of the study – thus providing a subpopulation, which was believed to have begun the 7-month test period free of any of the three tested protozoa. *Cryptosporidium parvum* is known to clear spontaneously in the vast majority of immunocompetent individuals and was therefore not treated. The results among the subjects tested both times, therefore, may be regarded as the rates of re-infection over the test period for test and control communities. The efficacy of treatment was confirmed by noting that only 8 (two in the test communities and six in the control communities) of 145 individuals (5.6%) who tested positive in February 2011 and were treated subsequently tested positive a second time.

In order to estimate the prevalence of positive stool tests, during June and July of 2010, a team of researchers collected a total of 160 samples from selected households in all six communities. Original estimates of the prevalence of abnormal stool tests (29%) had been based upon similar work in Honduras (Deal *et al.* 2010), however, the observed prevalence was around one half of that expected. In January 2011, construction of water treatment systems was completed in the three test communities. In February 2011, demographic surveys and stool samples were again collected from the same participants as well as additional participants with the age limit lowered to 3 years (total $n = 694$) in order to assure acceptable statistical power. Six months later, 77 subjects were no longer available for follow-up, most commonly due to relocation, pregnancy, or death resulting in a final population of 616 subjects.

Further information regarding diarrhea and dysentery rates was obtained by reviewing medical records from a public health clinic in a community where a water treatment system had been previously installed. All members of both test and control communities had access to a medical clinic, however, utilization was low in the four communities (two test and two control) where the clinic did not reside within the village. Interactions with the medical staff in this region were documented by a single line in a log book, which included name, age, gender, village of residence, diagnosis, and treatment. Researchers were given access to this data, which was then compiled within a spreadsheet to include all 19,490 visits for the prior 2 years. Comparisons were then made between visits for diarrhea or dysentery (858 cases of diarrhea and 58 cases of dysentery) between test and control communities.

ROLE OF THE FUNDING SOURCE AND ETHICS REVIEW

WMI maintains a country program in Uganda whose staff provided support and a significant amount of labor for this project. The study design, collection, and analysis of data and interpretation of the data were the sole responsibility of the corresponding author.

Consent and approval for this study was obtained by the Uganda National Council for Science and Technology, as well as the Uganda President's Office and WMI's Institutional Review Board. Under the supervision of a

licensed physician, all individuals in whom potential pathologic parasites were found were given free treatment. The control communities where no water treatment existed were selected from a pre-existing construction queue and intervention was not withheld as a result of this study. Verbal consent was obtained and recorded from all subjects.

ETHNOGRAPHIC RESULTS

The resulting ethnographic material included in excess of 2,500 videos and photographs, 16 focus groups, 142 loosely structured interviews including 110 hours of recordings and 427,345 words of transcription. Age and gender distributions for all subjects are found in Table 1.

In 2010, initial interviews with 142 subjects revealed a high level of knowledge regarding water and hygiene issues with all subjects mentioning without prompting that the lake water was not safe to drink. As seen in Table 2, despite this knowledge, the subsequent KAP survey revealed that 68% had consumed water from a source of unknown safety (87% in control communities and 53% in test communities).

Table 1 | Subject age and gender distribution of those participating in both the initial and final phases

	Total $N = 616$	Test communities $N = 317$	Control communities $N = 299$
Age group (%)			
3–5 years	15	16	13
6–12	29	26	32
13–17	10	9	11
18 +	46	49	43
Gender (%)			
Female	55	57	54
Male	46	43	46

In addition, sources of water for purposes other than drinking showed extensive use of lake water (see Table 3).

When asked about important health issues in the community without further prompting, malaria was mentioned 142 times (100% of interviewees) whereas diarrhea or dysentery was mentioned 78 times. Collectively, fever (separate from malaria) and/or cough were mentioned 60 times. HIV/AIDS was a major concern for the majority of subjects and was brought up unprompted 34 times, always with comments indicating knowledge of its frequency and severity. One subject, for instance, stated that 'We have all of these diseases, but AIDS has finished us'.

Knowledge regarding the purpose of using chlorine in water correlated strongly with the higher economic indicators $(X^2(1) = 16.12, \ p < 0.001)$, however, there was no significant difference in correct knowledge related to chlorine between test (52.7%) and control communities (51.3%).

MEDICAL RECORDS REVIEW RESULTS

The records of 19,490 patient visits to local healthcare facilities that occurred during the 5-month period since the test communities obtained access to treated water and the same months of the previous year when no treated water was available were reviewed. A diagnosis of dysentery or diarrhea accounted for 916 of these patient encounters. From 1 February 2010 until 30 June 2010 prior to any water system installation, in the test communities, 4.7 visits per thousand population occurred while 12.3 per thousand occurred in the control communities, indicating a higher burden of disease in the control communities existed prior to the intervention.

During the same months the following year, after installation of the water treatment systems in the test communities, a dramatic increase in visits for diarrhea and dysentery occurred in both test and control communities. For unknown

Table 2 | Water sources consumed in the past 72 hours

	Borehole (%)	Spring/well (%)	Lake (%)	Bottled water (%)	Rain collection (%)	Treated tap (%)
Control communities ($n = 78$)	52	18	12	11	6	2
Test communities ($n = 91$)	28	14	9	10	2	37

Subjects were allowed to choose more than one water source for each activity.

Table 3 | Sources of water for uses other than drinking ($N = 169$).

	Lake	Treated tap	Borehole	Spring or well	Rain water
Bathing	120 (71%)	19 (11.2%)	19 (11.2%)	9 (5.3%)	2 (1.2%)
Washing clothes	137 (81.1%)	14 (8.3%)	9 (5.3%)	8 (4.7%)	1 (.6%)
Cooking	99 (58.6%)	29 (17.2%)	26 (15.4%)	13 (7.7%)	2 (1.2%)
Washing utensils	112 (66.3%)	28 (16.6%)	16 (9.5%)	11 (6.5%)	2 (1.2%)

Subjects were allowed to choose more than one water source for each activity.

reasons, visits for these causes increased by 6.07 times in the test communities and 6.54 times in the control. While the increase was greater in the control communities, the incident rate differences of 0.388 in 2010 and 0.360 in 2011 were not statistically significant. We therefore concluded that the differences in the clinic visits for diarrhea or dysentery between test and control communities (fewer in the test communities) could not be attributed to the water treatment intervention. As of the time of this writing, no explanation for the increase in diarrhea and dysentery rates in all communities in 2011 has been identified.

KAP SURVEY RESULTS

At baseline prior to installation of systems, 30% of the participants in the test communities (where treatment systems were to be installed) reported having diarrhea compared to 18.5% in control communities. Age-adjusted odds ratios (ORs; odds of disease in the test community versus the odds of having a disease in the control community) were calculated by logistic regression. Age, a known risk factor for diarrheal disease, was adjusted for when calculating the ORs of disease outcomes to help control for potential confounding that may have resulted from the different age structures between the test and control groups. The odds of self-reported diarrhea were found to be significantly higher in the treatment group than the control group [$OR = 1.86$, 95% confidence interval (CI) (1.27, 2.72)]. While the percentage of self-reported diarrhea remained about the same in the test communities even after installation, the percentage increased from 18% to 35% in control communities. There was no significant difference in self-reported diarrhea at the end of the study between test and control groups [$OR = 0.084$, 95% CI (0.6, 1.2)]. However,

the OR of self-reported diarrhea between test and control communities significantly increased during the 6-month period of this study with the greatest increase occurring in the control communities. Among individuals who reported diarrhea at baseline, a larger percentage recurred in control (52.7%) compared to test (33.3%) communities ($X^2(1) = 5.39$, $p < 0.02$) at follow-up. In these individuals, the odds of diarrhea at follow-up remained elevated for control communities compared to test communities after age adjustment [$OR = 2.21$, 95% CI (1.12, 4.39)].

Age, economic status (as indicated by the economic scale described earlier), distance to the safe water distribution point, and distance to the lake did not correlate to the self-reporting of diarrhea.

PARASITE IMMUNOASSAY RESULTS

The combined prevalence of the parasite tests is found in Table 4. The overall prevalence of positive parasite tests at the beginning of the trial before the water treatment systems were active was 20.8% (23% in test communities and 18% in control communities). No cases of *Cryptosporidium* were detected. *Giardia* accounted for 57.9% of the positive tests in the initial round of tests and 52% in the final round of testing while *Entamoeba* accounted for the remainder.

Similar to the self-reported diarrhea results, there was a higher odds in the test group for having *Giardia* at the start of the study [age-adjusted $OR = 1.68$, 95% CI (1.03, 2.73)]. Although the percentage of participants with *Entamoeba* was higher in the test group than the control group at the start of the study, this difference was not found to be significant [$OR = 1.14$, 95% CI (0.66, 1.97)]. All of these subjects received appropriate doses of tinidazole.

Table 4 | Initial and final (measured 5-month after installation of water systems) water-borne disease prevalence measured by self-reported diarrhea and rapid tests (*Giardia lamblia, Entamoeba histolytica,* and *Cryptosporidium*)

	Total N = 616 (%)	Test communities N = 317 (%)	Control communities N = 299 (%)
Self-reported diarrhea initial	24.2	29.7	18.4
Self-reported diarrhea final	32.8	30.7	35.1
Giardia lamblia initial	12.4	14.2	10.4
Giardia lamblia final	8.9	9.8	8.0
Entamoeba histolytica initial	9.4	10.1	8.7
Entamoeba histolytica final	7.8	8.9	6.7
Cryptosporidium initial	0	0	0
Cryptosporidium final	0	0	0
Any positive rapid test initial	20.7	23.1	18.1
Any positive rapid test final	16.6	18.7	14.4

On return 7 months later, 616 subjects (88.7%) were available for follow-up (299 in control communities and 317 in test communities). Positive tests for any of the parasites were found in 43 (14.4%) subjects within the control communities and 59 (18.7%) within the test communities. The difference in control versus test community 7-month incident rates (based upon final results and assuming no treatment failures) was not statistically significant ($X^2(1) = 2.13$, $p = 0.14$). At the end of the study period, there was no difference detected in the odds of either *Giardia* [OR = 1.36, 95% CI (0.77, 2.40)] or *Entamoeba* [OR = 1.34, 95% CI (0.74, 2.22)] in test groups compared to control groups.

Further stratification of the data was performed by age groups, gender, economic status, distances to the lake, distances to the treated water tap, and education levels, and again, no statistically significant differences were observed in test versus control communities within any of these groups.

DISCUSSION

This paper represents an extension of a study in Honduras using similar methods (Deal *et al.* 2010). To our knowledge,

these are the first studies to combine self-reported data, medical chart review, and stool immunoassays as measures of the health impact of water treatment systems. The triangulation of these methodologies provides powerful evidence for what are otherwise strongly subjective and questionable measures of disease loads from waterborne pathogens. In Honduras, significant improvements were noted in the medical chart reviews, parasite levels, and in ethnographic descriptions of well-being and health. It is of interest, therefore, that this larger study in Uganda failed to find significant differences in the control and test communities in all but the self-reported diarrhea.

Ethnographic data revealed a high level of understanding of water and hygiene issues, raising doubts about the efficacy of ongoing efforts to change behavior by increasing education efforts. Also, water and sanitation related diseases were of relatively low priority among participants when compared to malaria, HIV/AIDS, or tuberculosis. Knowledge regarding waterborne illnesses did not correlate with effective behavior to prevent those diseases – a finding that warrants further investigation.

Unlike the present study, immunoassay evidence of decreased prevalence of waterborne parasites in Honduras strongly supported the contention that community-based water treatment facilities reduced the overall stool parasite load, at least of the three protozoan species tested. Since all subjects who tested positive for either *Giardia* or *Entamoeba* were treated with effective doses of tinidazole adjusted for age and weight, the follow-up study of all subjects who submitted stool samples in the final round of tests is felt to represent the re-infection rates, in essence eliminating concerns regarding residual colonization from exposures that occurred prior to initiation of this study.

Ethnographic and KAP survey data suggest multiple potential explanations for the limited observable effects from the provision of water treatment systems in this specific location. First, and likely the most powerful confounder, is the presence of Lake Victoria itself. The lake is known to be highly contaminated by urban, industrial, and agricultural wastes. Schistosomiasis rates, a condition contracted by skin contact with infested waters, are high in areas surrounding the lake and have been directly correlated with proximity of inhabitants to its shores (Handzel *et al.* 2003). This confirms ethnographic observations that inhabitants

of the study communities come into contact with contaminated water frequently by washing themselves, their children, clothes, and kitchen utensils in the lake. Also, the majority of the cooking areas observed in all of the communities were outside and domestic animals frequently ate, grazed, and defecated close to where food was prepared and consumed. Children and adults were observed on multiple occasions taking water from the lake in containers as well as drinking directly from the lake, even in communities where treated water was readily accessible.

All six of the study communities had at least two or more drug shops where antibiotics and antimalarial medications were given without direct medical advice. Doxycycline and artesunate-based medications, the most commonly dispensed antimicrobials, both have limited activity against protozoans (Mahmoud & Nessim 2008). Diarrhea is also a common complication of all antibiotics. Local healthcare providers informed us that mass de-worming programs were performed up to four times per year in the study area, and there is evidence that the medication most commonly used, albendazole, is also active against at least some gastrointestinal protozoan (Karabay *et al.* 2004). The effect of these drugs used widely within the test and control communities would also tend to blunt attempts to measure any potential impact of the water treatment system by potentially increasing rates of diarrhea and decreasing parasite incidences.

CONCLUSION

While the technical components of this water project were successfully accomplished, these findings suggest that more is required in this region in order to achieve improvements of health by such interventions. Selection of study subjects by screening for only those who are compliant with health and hygiene training efforts was not done in this project. We would suggest such surveys would be of questionable value. The issue we attempted to address here was the efficacy of the 'strategy' of installing community-based water treatment facilities, not the efficacy of the technology to eliminate microbiological contaminants as the filtration systems coupled with chlorination have been of proven efficacy for decades. Issues of post-treatment recontamination of water prior to consumption remains an additional possibility, however, the presence of residual free chlorine at the time of dispensing makes this less likely.

The test communities in this study had ready, cheap, and convenient access to water that meets US safety standards, and yet, we could detect only limited improvements in their health. There is no credible reason to doubt that drinking biologically contaminated water causes diseases and that drinking only pathogen-free water is safer. This study is in contradistinction to our own work in Honduras as well as a wealth of prior work related to waterborne diseases and is significant in that it points to an inescapable fact: human health is an irreducibly complex puzzle. One cannot expect to consistently find improvements of health metrics by correcting only one piece of this puzzle. We already know how to treat water at low cost and in vast quantities. For these reasons, we would suggest that the major advances in managing the enormous disease loads caused by waterborne illnesses and hygiene will be socioeconomic and not technological. Water issues and management represent a field in which anthropological inquiry, as a part of multidisciplinary approaches, must play a central role.

Caution must be exercised in extrapolating this study to suggest that efforts such as the water project represented here are without merit or are not 'cost effective'. Clearly, a lack of detectable health improvements creates potential public relations issues for non-governmental organizations dependent upon donations, however, the intellectual integrity and courage required to seriously study this issue and support publication of even negative results should be applauded and replicated. Access to safe water is just one of many components required for health. It should be self-evident that organizations should not withhold this critical resource solely, because all of the other components for health cannot also be provided. Put simply, it would be wrong to do nothing because we cannot do everything.

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