ABSTRACT

The Effects of Water Quality on Growth in Children on Kenya's Nyakach Plateau

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Poor water quality is one of the many problems that affect developing nations and contributes to the virtually inescapable cycle of poverty in which the world's impoverished are trapped. Straw to Bread, a 501(c) 3 nonprofit organization based in the United States, has attempted to mitigate this issue among the Luo people of the Nyakach Plateau in Kenya's Nyanza Province by installing rainwater collection tanks in poor households. The present study was conducted to evaluate the relationship between the use of these tanks and Body Mass Index (BMI) among children on the Plateau. Measurements were taken on site from children with tanks and without tanks in May, 2013. Other data were collected via survey from the head of each household. Ultimately, it was demonstrated that, after adjusting for environmental factors, age, and sex, there was a positive dose-response relationship between water quality and BMI in girls (R^2=0.47, $p<0.0001$) but not in boys (R^2=0.10, $p=0.4970$). While further investigation is needed to understand this discrepancy, the results of this study demonstrate the importance of clean water access in underserved populations and will guide the continued intervention of Straw to Bread in the area.

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THE EFFECTS OF WATER QUALITY ON GROWTH IN CHILDREN ON KENYA'S NYAKACH PLATEAU

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By

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CHAPTER ONE

Introduction

A plethora of conditions separates developing countries from developed countries in today's world. Many countries lack the infrastructure that developed countries have; this problem is especially evident in terms of healthcare systems, which in developing countries are almost invariably understaffed and underfunded (Crisp 2010). Political systems often create or facilitate the outright oppression of their peoples. Extreme poverty is rampant, and public health issues addressed far in the past for developed countries continue to plague developing countries (Farmer 2005). Among these issues is water safety: access to clean, safe water for drinking, cooking, and cleaning is essential to health. Sub-Saharan Africa is plagued by limited access to water for many of the reasons described above. In most cases, countries in this region lack the basic transportation and storage infrastructure that more developed countries have. The United Nations Environment Program states that the problem of limited access to safe water is worse in Sub-Saharan Africa than in anywhere else in the world. Kenya, a victim of the problem of poor infrastructure, experienced a drought at the turn of the century that decimated its economy (CFR 2013). Rural water sources were the last ones targeted by subsequent water reform (WSP 2011). In rural western Kenya, groundwater sources are heavily contaminated. The pathogens commonly found in contaminated groundwater in this area of the world can be very detrimental to the health of an individual and have been directly or indirectly associated with lower Body Mass Index values in children.

For the people of rural western Kenya, access to safe water sources is not a new struggle. A 2001 study by Makutsa et al. found that in 1999, 66% of the inhabitants of the Nyanza Province, the area in which the present study was conducted, lacked access to safe water (Makutsa et al. 2001). Furthermore, the depletion of safe water sources frequently leads people to seek water from unsafe sources (Simiyu et al. 2010).

Straw to Bread is a nonprofit organization based in the United States dedicated to serving the inhabitants of the Nyakach Plateau in rural western Kenya. The organization aims to improve the lives of these people through the promotion of sustainable socioeconomic development. Straw to Bread is aware of the poor water quality in the region and the hazards with which it is associated, and in response it funded the construction of 48 rainwater collection tanks in the area in 2011. These tanks were distributed among the poorest households on the Plateau. The relatively concentrated and uniform population was a useful condition for studying the effects of this intervention on the health of the community.

CHAPTER TWO

Review of Literature

In less-developed countries, many people struggle to simply obtain basic resources. A 2007 study identified that 86.1% of in a rural western area of Kenya were in the lowest economic quintile (MMWR 2007). Lack of access to many things like adequate nutrition, proper medical care, and clean water has led directly and indirectly to poor growth in children living in these countries. Poor nutrition, poor health, and poor water quality each contribute to the inhibition of growth; the literature is very clear on each of these relationships. However, there is much more research on food- and health-based interventions than on water-based interventions. Because of the contaminants and pathogens found in groundwater in rural, western Kenya, even the health benefits of access to adequate nutrition can be nullified by unsafe water consumption and exposure.

The present study seeks to investigate an intervention designed to provide the people of Kenya's Nyakach Plateau with clean water via the installation of rainwater collection tanks. Most studies have evaluated the success or failure of water-quality interventions based on an analysis of the pathogens that remain or based on symptoms that persist, such as diarrhea. There is a need to evaluate whether the everyday, practical use of the water actually has a positive effect on children's growth. It is clear that lack of food and poor health are crucial, but it is not clear whether an intervention with water alone could ameliorate these other problems to the extent that a measurable difference is seen in children's growth. The positive effect of water quality itself, in addition to its impact on decreasing illness, should both be measured in order to fairly assess this complex interaction and identify how effective clean water actually is.

Hazards Associated With Groundwater: An Overview

Several types of bacteria, viruses and parasites have been implicated in the relationship between water quality and illness. A survey of groundwater sources outside of Kisumu, Kenya showed that most sources, regardless of whether or not they were structurally protected, were unsafe for human use. Furthermore, 95% of these sources were found to contain Escherichia coli (Opisa et al. 2012). E. coli seems to be a widespread contaminant, as a survey in the eastern portion of the country also revealed that most groundwater sources were contaminated with E. coli (Leiter et al. 2013). Unsafe levels of intestinal enterococci have been identified in rural Kenyan groundwater (Yillia et al. 2009). Vibirio cholerae has been shown to be present in Lake Victoria and streams feeding into it (Shapiro et al. 1999). Rotaviruses have been found in river water in both rural and urban areas of Kenya (Kiulia et al. 2010). Muchiri and colleagues. (2009) have shown that cryptosporidia are present in groundwater sources across Kenya. While schistosomiasis is a zoonotic infection, exposure to contaminated water can still result in infection (Hotez 2008). In the Machakos district of Kenya, schistomiasis infection was associated with groundwater exposure (Kloos et al. 1997). Schistosomiasis is also very prevalent on the shores of Lake Victoria (Handzel et al. 2003, Odiere et al. 2012), but has been shown to extend into rural areas outside of Kisumu (Opisa et al. 2011). In studies of diarrheal illnesses in rural Kenya, severe bloody diarrhea can be caused by salmonella, shigella, rotavirus, giardia, and campylobacter infection, all of which are associated with consuming contaminated water (Saidi et al. 1997, Brooks et al. 2003). Furthermore, the consumption water containing the eggs of *Ascaris lumbricoides* and *Trichuris trichiura* can lead to infection by these organisms (WHO 2013). Given the presence of these infections in rural Kenya, it is reasonable to assume that groundwater sources could be contaminated with these eggs (Handzel et al. 2003, Odiere et al. 2012). The ties of these pathogens to poverty—through poor water or nutritional quality—make them difficult to escape.

Risks due to Bacteria and Viruses

Escherichia coli are bacteria that cause a substantial amount of mortality in Kenya. While certain strains of E. coli are part of normal intestinal fauna, other strains are capable of wreaking havoc inside the body (CDC 2013). E. coli alone has been found to cause 30% of the diarrhea cases among the Maasai tribe in southern Kenya (Sang et al. 2012). Many strains of E. coli in Kenya are becoming resistant to multiple antibiotics, including ampicillin and tetracycline, which is a hazard to those for whom medical care is hard to come by (Sang et al. 2012).

Cholera is a waterborne bacterial illness that causes severe diarrhea and nearly one hundred thousand deaths worldwide per year (CDC 2013). It has a 25%-50% mortality rate when left to its natural course (Fournier & Quilichi 2007). A 2001 study in rural western Kenya revealed cholera presence in 18% of 244 stool samples from subjects with diarrhea (Shapiro et al. 2001).

Salmonella can enter the body through contaminated water (Hohman 2001). It was present in 22% of stool samples in a study of 107 Kenyan child hospital deaths (O'Reilly et al. 2012). The infection not only causes diarrhea but can spread to cause vascular and deep bone infections. Especially problematic is the emergence in the last two decades of antibiotic-resistant strains of salmonella, creating an even worse situation for those living in regions where healthcare is in limited supply. Given the proclivity of Salmonella to infect immunocompromised individuals, the prevalence of HIV in the study region could likely present a serious hazard (Hohman 2001).

Campylobacter is a waterborne bacterial illness that causes diarrhea, fever, cramping, and a skin infection (Pacanowski et al. 2008). It, too, is especially effective in attacking immunocompromised individuals. A 2001 study in rural western Kenya revealed campylobacter presence in 30% of 244 stool samples from patients with diarrhea (Shapiro et al. 2001). While diarrhea is the effect most germane to the present study, campylobacter infection can also cause an autoimmune attack on the body's nervous system called Guillain-Barre. Lack of access to medical care in developing areas is particularly problematic in this regard, as this paralysis requires several weeks of intense treatment (CDC 2013).

Rotaviruses cause severe diarrhea, fever, gastroenteritis, and dehydration and are responsible for more than 500,000 deaths per year. The ability of these viruses to be transmitted through water is due to their stability in the environment (CDC 2013). In a 2008 case-control study in a hospital in Kenya's Kalifi District, rotavirus was found in 29% of 2,039 tested diarrhea cases but only in 3.1% of 620 non-diarrhea controls. Rotaviruses are especially significant to the present study because they alone are responsible for 28,000 hospitalizations a year in Kenya (Nokes et al. 2008).

Risks due to Parasite Content

Ascaris and Trichuris are two soil-transmitted helminths (STH's) that have been present in the human population for thousands of years, and they are responsible for 807 million and 604 million infections today, respectively. Helminths produce eggs inside the human intestine, which later exit the body with feces (Hotez 2008). The proximity of many groundwater sources to pit latrines in rural western Kenya certainly presents an opportunity for these eggs to come in contact with humans. The importance of these parasites to the study at hand is established by a study of 1246 Luo children in primary schools near Lake Victoria, in which soil-transmitted helminth infection prevalence was found to be 63%. Risk factors for infection included swimming and collecting water (Handzel et al. 2003). Helminthic infections have been shown to affect mental functioning, and seem to affect children much more than adults. (Hotez 2008). This is especially significant in the context of poverty, as education can be a tool that breaks the cycle of poverty. If a child cannot do well in school as a result of a helminthic infection, he would have a difficult time acquiring the money that would help him get and stay healthy. Intense ascariasis can lead to intestinal blockage, and the inflammation resulting from trichuriasis can lead to rectal prolapse. STH's are considered to be the "world's leading cause of growth retardation and stunting," making them particularly important when assessing a relationship between water quality and BMI (Hotez 2008).

Schistosomes are also shown by Handzel and his colleagues (2003) to be a threat to schoolchildren in Kenya. Schistosomiasis in rural western Kenya comes in two varieties, Schistosoma mansoni and Schistosoma haematobium. Adult schistosomes lay eggs in water, and when these eggs hatch, miracidia take up residence in a host snail.

Schistosomal sporocysts proliferate inside the snails and eventually are released into the water, where they are then able to invade a human host. The schistosomes mature and migrate to the gastrointestinal tract of the host. Adult female schistosomes produce hundreds of eggs per day, which become lodged in the bladder or intestine, causing obstruction and damage. The bleeding as a result of this damage is known to cause anemia and chronic pain (Hotez 2008). Studies of Kenyan schoolchildren confirm this association (Koukounari et al. 2008). Anemia severity has been positively correlated to schistosomal infection intensity (Butler et al. 2012). Similarly to the STH's described above, schistosomiasis reduces academic and cognitive performance (Hotez 2008, Jukes 2002). Among Luo schoolchildren, the prevalence of schistosomiasis can be as high as 16.3% (Handzel et al. 2003). In western Kenya, prevalence tends to increase with proximity to Lake Victoria (Lwambo et al. 1999, Odiere et al. 2011); some studies reveal prevalences higher than 20% (Pullan et al. 2011).

One of the most frequently found fecal parasites in western Kenya is Cryptosporidium (Ngindu et al. 2002). Cryptosporidia take up residence in the gastrointestinal tract, where they produce oocysts which are excreted with feces. These oocysts can infect humans either through direct contact with or consumption of contaminated water (CDC 2010). Cryptosporidiosis is one of the top four causes of diarrhea in Kenyan children. Moreover, 86% of cryptosporidiosis cases occur in rural areas, making this illness, geographically speaking, particularly important to the study at hand. In addition to diarrhea, cryptosporidiosis is known to cause abdominal pain, vomiting, and persistent functional deficits in children (Gatei et al. 2006). A symptom of Cryptosporidiosis pertinent to the present study is weight loss (CDC 2010).

Hookworm is a soil-transmitted helminth that is present in western Kenya (Odiere et al. 2012). Unlike the other helminths described above, it can generally not be transmitted orally (WHO 2013). Instead, hookworm is spread through the feces of infected individuals that contain the eggs, and larvae enter humans via the skin (CDC 2013). A 2010 study of schoolchildren in the Nyanza province by Riesel and colleagues (date) found that the prevalence of hookworm infection was 30%. Hookworm is associated with anemia like many of the other pathogens mentioned above (Brooker et al. 1999), giving it the ability to contribute to variance in BMI values in ways that water quality does not.

The Effects of Malnutrition and Food Insecurity

In regards to nutritional problems in the developing world, the Food and Agriculture Organization of the United Nations (FAO) emphasizes three major factors in good nutrition: "food security, good health and adequate care." While the FAO elaborates upon each of these, the organization is clear in stating that a nutrition-centered approach is the only effective means of global nutritional improvement (FAO 2013). Indeed, individuals have little potential for good health if they lack access to even the most basic nutrients or food sources.

In fact, poor nutrition can easily nullify the effects of good health—several researchers have described a vicious malnutrition-infection cycle, in which poor nutrition creates susceptibility to infections and subsequent infections cause and worsen malnutrition (WHO 2013, FAO 2013, Katona & Katona-Apte 2008, Guerrant et al. 2008). For example, schistosomiasis has been shown to interact synergistically with nutritional status to impair growth (Orsini et al. 2001).

Food insecurity has also been positively correlated with anemia among young children (Campbell et al. 2011, Ahmed et al. 2012). The fact that anemia is associated with lower BMI values, combined with the fact that food insecurity is positively correlated with anemia, further supports the notion that dietary influences are important. The relationship between anemia, nutrition, and BMI is substantiated by the fact that children participating in school feeding programs are less likely to show stunting or wasting and are less likely to have anemia (Neervoort et al. 2012). Diarrhea has also been associated with poor nutritional status in Kenya (Gewa et al. 2012). Chronic diarrhea and malnutrition have been shown to interact with each other; while diarrhea depletes the body's nutrient store, malnutrition also hinders a body's ability to recover from diarrhea, ultimately worsening and prolonging diarrhea (Patwari 1999). Given diarrhea's potential to affect growth, this is another route by which nutritional status can affect BMI values.

As in most developing countries with a sizeable rural population, protein-energy malnutrition (PEM) is a significant problem in Kenya. This specific type of malnutrition, as its name indicates, comprises a dietary deficit of caloric and protein intakes. According to the WHO, PEM is "by far the most lethal form of malnutrition" and manifests itself in a severe incapacitation of growth, as noted below (Mach 2000). As of 2005, the FAO estimates that within the rural population of Kenya, 21.3% of children exhibit low to moderate underweight (low weight-for-age) and 31.7% exhibit low to moderate stunting (low height-for-age) (FAO 2005). Both of these measurements are consistently correlated with protein-energy malnutrition, along with wasting (low weight-for-height) (Jamison 2006). These correlations exist to such an extent that underweight, stunting, and wasting are used in research as reliable indicators of PEM

(Muller & Krawinkel 2005). Indeed, the FAO states that their anthropometric determinants—height and body weight—are most important in diagnosis of PEM (FAO 1999). It is then likely that malnutrition, specifically protein-energy malnutrition, would affect BMI through its modifications of growth. In addition, in its food-based approach to nutrition in developing countries, the FAO emphasizes a diverse diet, consisting of adequate amounts of both macronutrients (carbohydrates, fats and protein) and micronutrients (vitamins, minerals and other trace elements) (FAO 2013). Diets lacking in either macro- or micronutrients have adverse effects upon bodily growth and development (FAO 2013). Diet diversity, as described above, has been inversely correlated with lower BMI values (Savy et al. 2005). Thus, PEM, macro- and micronutrient deficiencies, and other indices associated with malnutrition (including food security) would be controlled for in the current study. However, the population in the study area is so homogeneously poor that food insecurity is ubiquitous and that little diet variety exists, particularly among children. Variation in nutritional status, likely to be a significant factor in other areas, is therefore unlikely to confound any relationship found between water source and BMI found by the present study.

Health Status and its Influence on Growth

The most serious health problems that affect growth in this region are malaria, HIV, and anemia. Malaria status is an important consideration in evaluating children's growth in areas of high prevalence, and this disease has particular relevance with regard to installing water tanks—a new source of standing water for mosquito breeding. A parasitic infection carried by the anopheles mosquito, malaria is a highly destructive illness; kidney failure, cardiovascular collapse, acute respiratory distress syndrome, and metabolic acidosis are all documented problems that result from this parasite. Malaria has been associated with anemia in Kenya (Newton et al. 1997, Desai et al. 2005) and could also contribute to variance in BMI. Parasitemia has been associated with lower malarial intensity but more severe anemia in Kenyan children with malaria (Were et al. 2011). The importance of malaria status is seemingly boosted by the fact that malaria has been shown to interact synergistically with helminthic infections to exacerbate anemia (Brooker et al. 2007), yet confusion arises as others have found that malarial co-infection with helminths reduce a person's chances of anemia (Melo et al. 2010). Moreover, blood presence of malaria parasites has been directly associated with lower BMI values in adolescents and adults in western Kenya over a 16-week period (Friedman et al. 2003) and associated with stunted growth over a 21-month period (Hautvast et al. 2000).

Human Immunodeficiency Virus (HIV) status is another potentially important influence on growth in high-prevalence areas like Kenya. In fact, HIV has been shown to interact with malaria (Antelman et al. 2000). Also, HIV infection intensity has been positively correlated with the prevalence and severity of anemia, and reduction of anemia has been shown to produce better HIV outcomes (Belperio et al. 2004). HIV-positive children have been shown to have a higher incidence of diarrhea than HIV-negative children. HIV positive-status has also been directly associated with lower BMI values (Justman et al. 2008).

Clearly, anemia is a very important factor in the context of the relationship of water quality to BMI. Children with anemia have been shown to have lower BMI values than non-anemic children (Solimann et al. 2009), and one of the causes of the anemia may be the effects of the organisms described above through microscopic blood loss and the parasites stealing the nutritional components that make up red blood cells. This relationship between anemia and low BMI is substantiated by interventional studies that show that iron supplementation improves growth in anemic Kenyan schoolchildren (Latham et al. 1990). Furthermore, in a study of Colombian women, a negative correlation between BMI and anemia prevalence was found (Kordas et al. 2013).

One more element of this complex web of interaction is that some of the bacteria, viruses, and parasites discussed above above cause diarrhea, which are is also associated with an increased risk of anemia (Howard et al. 2007, Semba et al. 2008). Diarrhea can account for 14% of hospital visits in rural Kenya (Burton et al. 2011). One must be cautious in attributing low BMI values to diarrhea, as Poskit et al. (1999) found that a reduction of the incidence of diarrhea in a community in Gambia by 22% did not result in increased growth. However, Poskit and his colleagues measured diarrhea using clinic visitations; this method of measurement does not account for whether or not diarrhea was acute or chronic. This distinction is important to make, as chronic diarrhea, not acute, is associated with anemia (Frisancho et al. 1994). Also, the elimination of diarrhea might not be enough to counter the other potent causes of anemia that remain, such as poor nutrition.

A common health behavior associated with these conditions is geophagia, as eating soil has been associated with diarrhea (Shivoga et al. 2009). Geophagia has also been strongly associated with anemia in Kenyan schoolchildren (Geissler et al. 1998). Finally, geophagia can lead to the unintentional consumption of worms or parasites, an observation that brings us full circle as to the complexity of the nature of growth in children.

Interventions and Implications

Simple things such as handwashing with soap have been shown to reduce the incidence of waterborne illness (Cairncross et al. 2010). Another method is the solar disinfection of water, in which water is stored in plastic bottles and left in the sun. This method has been shown to be effective at reducing the incidence of diarrhea (Conroy et al. 1996). Pasteurization has also proven to be effective at improving water quality. In a study in Kenya, pasteurization accounted for the quadrupling of the number of households with fecal-coliform-free drinking water (Iijima et al. 2001).

A study in Ghana examined the effects of a water recreation area fed by rainwater as opposed to groundwater. The investigators found that the installation of the water recreation area reduced transmission of schistosomiasis (Kosinski et al. 2012). As this disease is readily transmitted through any kind of contact with schistosome-infested water, the installation of rainwater tanks should limit the exposure of people to parasites. However, rainwater collection tanks are not necessarily an answer to the water safety problem. The results of a south Australian study indicate that children consuming untreated rainwater were still at higher risk for diarrhea than controls drinking treated mains water (Heyworth et al. 2006). Other studies also find E. coli present in rainwater collection tanks, though these E. coli levels were brought within safe range by filtration (Nawaz et al. 2012). Water filters are also very likely to be effective. In a randomized, controlled trial of ceramic water filters in rural South Africa and Zimbabwe, investigators found that members of households using a filter experienced fewer episodes of diarrhea (Preez et al. 2008). Studies have shown that most people given a water filter use it consistently over time (De ver dye et al. 2011). As is the case with rainwater collection tanks, filters alone are likely not a water-quality panacea. For example, studies of less expensive roughing water filters—devices that remove suspended solids from liquids—show that they are not completely effective at removing Ascaris eggs from water (Nouri et al. 2008).

The use of rainwater collection tanks presents a risk of introducing more malaria into a community. In an Indian study, mosquito larvae were identified (by raising to adulthood in lab) in one quarter of studied water tanks (Mandal et al. 2011). This problem is also suggested by the fact that in rural Ethiopia, the installation of rainwater harvesting systems was linked to an increase in malaria incidence (Waktola 2008). When the current intervention was made on the Nyakach plateau, careful instructions were given to keep the tanks closed except during times of rain. This study presents the opportunity to see if, in fact, the tanks have been maintained in that fashion and if the malaria prevalence is increased among tank-users compared to other residents in the area who use groundwater.

Conclusion: The Gap in the Literature

As long as water security is a threat to the children of rural western Kenya, many of these issues will continue to affect their lives. A drink of water taken to stay alive will always have the potential to be a death sentence for some. The waterborne illnesses discussed above have the potential to perpetuate a child's poverty by hindering nutrition, educational performance, and physiological functioning. Ultimately, poor water quality has the potential to affect growth. All of these detriments might work synergistically with health status and nutritional deficits to harm a child. Stopping this phenomenon is of great interest to Straw to Bread, which has attempted to provide the Luo people with at least some improved water quality with rainwater collection tanks. This community-based research seeks to evaluate how effective this intervention is in general and how well it has worked in this particular community of Luo children. The literature, as discussed above, is very clear on the hazards of contaminated water. What the literature lacks is an evaluation of the impact of rainwater harvesting as an alternative to groundwater use on the growth of children, while adjusting for health status. If the installation of these water tanks can improve the health of those who use them, the results of the study will not only serve to inform the actions of Straw to Bread, but they will also contribute useful information to the global health research community.

CHAPTER THREE

Hypotheses

Description of Study

This study examined the relationship between water quality and BMI in children in rural, western Kenya using a cross-sectional design. Water quality was operationalized by dividing water sources into tank and non-tank sources. Anthropometric measures were taken using a tape measure and portable scale and were used to calculate BMI. Using a survey, the ways in which a household used water were also recorded. As such, the study aimed to determine "water use" variables, such as non-drinking usage and duration of the tank water supply, that modify the relationship between water source and BMI in children. To account for potential confounders, age, gender, socioeconomic status, and health status were adjusted for. These relationships are outlined in Figure III.A.

Research Questions

Primary Research Question:

After adjusting for age, gender, education, and health status, do poor children with access to clean drinking water achieve BMI values similar to those of their better-off counterparts?

Hypothesis: After adjusting for nutritional status, age, gender, education, and health status, poor children with access to clean drinking water will achieve BMI values similar to those of their better-off counterparts.

Null Hypothesis: Children in the tank group will have a lower BMI than that of children in the non-tank group. That is, the growth of children in poorer homes will not have caught up with that of children living in better homes.

Secondary Research Question 1:

When looking at variables describing a person's use of a water tank, does non-drinking use, boiling, or duration of clean water supply influence growth the most?

Hypothesis: After adjusting for age, gender, and education, the duration of the clean water supply will influence growth in children more than boiling or non-drinking use.

Null Hypothesis: There will be no difference between the effects of non-drinking use, boiling, and duration of clean water supply.

Secondary Research Question 2:

After adjusting for age, gender, socioeconomic status, education, and health status, do environmental variables, such has housing quality, use of a mosquito net, or place of cooking have any impact on BMI in children?

Hypothesis: After adjusting for age, gender, and environmental factors, better water quality will be associated with better health outcomes in children.

Null Hypothesis: There will no difference in BMI caused by environmental variables.

Secondary Research Question 3:

After adjusting for age, gender, socioeconomic status, and education, do health outcomes (i.e. diarrhea, malaria) affect BMI in children?

Hypothesis: After adjusting for age, gender, and environmental variables, poor health outcomes are associated with a lower BMI in children.

Null Hypothesis: There will be no relationship between health outcomes and BMI values.

Secondary Research Question 4:

After adjusting for age, gender, socioeconomic status, and education, do water quality variables have any impact on health outcomes?

Hypothesis: After adjusting for age, gender, and environmental factors, better water quality will be associated with better health outcomes in children.

Null Hypothesis: There will be no effect of water quality on health outcomes.

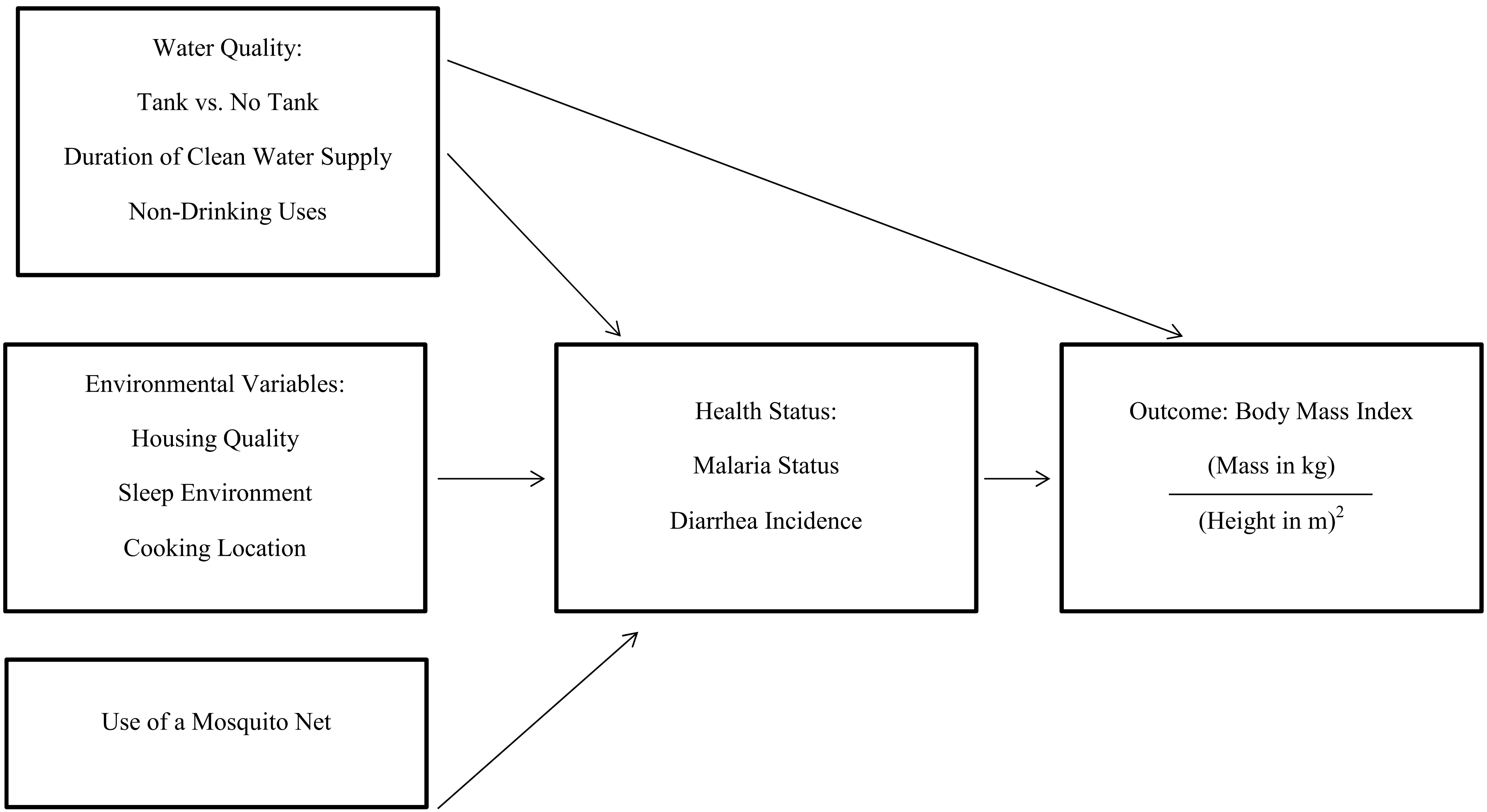
Secondary Research Question 5:

After adjusting for age, gender, socioeconomic status, and education, do environmental variables, such has housing quality, use of a mosquito net, or place of cooking have any impact on health outcomes in children?

Hypothesis: After adjusting for age, gender, and environmental factors, better environmental conditions will be associated with better health outcomes in children.

Null Hypothesis: There will be no impact of environmental quality on health outcomes in children.

Figure 3-1: Study Path Model



CHAPTER FOUR

Methods

Setting

Straw to Bread is a US-based nonprofit organization that sponsors a team that works for two weeks each year on the Nyakach Plateau in rural western Kenya among the Luo tribe. This annual activity is part of ongoing development projects and research in this area that encompass healthcare, food and sustainable agriculture, safe water sources, education, and small business development. This study focused specifically on safe water sources and their relationship to BMI in children. A child in this study was defined as being under the age of eighteen.

Sample

There are 64 water tanks distributed among the inhabitants of the Nyakach Plateau. Data were collected from as many subjects as time allowed (n=179) using a convenience sample.

The control population was also sampled via a convenience sample. Children in households not using water tanks located near experimental households were assessed. Households were included in the control group if they were located near experimental households and relied on groundwater as their sole source of water.

Exclusion Criteria

Data were collected from as many subjects as possible over a two-week period. However, time did not allow for data to be collected from all subjects, so these were excluded from the study. Subjects were also excluded from the study if they were older than 18. Additionally, school was in session for much of the time data were being collected, so children who were at school during the time of data collection were also excluded.

Research Design

This was a cross-sectional study attempting to establish a statistically significant relationship between water quality and Body Mass Index.

Measurements

The predictor variable in this study was water quality. While the idea of water quality encompasses many different areas (bacteria, virus, heavy metal, or waste content), water quality in this study was operationalized as the presence of a water tank, the number of non-drinking uses of tank water (for tank users) and the duration of the tank water supply (tank users). The water usage practices of a household were assessed using the questionnaire in Appendix I.

The outcome variable in this study was Body Mass Index. Body Mass Index is measured by dividing a person's weight in kilograms by their height in meters squared. Height measurements were taken using a tape measure, and weight measurements were taken using a portable scale.

Age, sex, HIV status, malaria status, and use of other water sterilization methods were adjusted for. All of these factors were assessed in the questionnaire in Appendix I.

Statistical Analysis:

Data collected from the study were double-entered into Microsoft Excel and then imported into SAS 9.3, the statistical program that was used in data analysis. Frequencies, percent and cumulative percent, mean and standard deviation (where applicable) were reported for each variable. Data were stratified by HIV status, malaria status, nutritional status, age, and sex.

To test measures of association, contingency tables were used for discrete variables using odds ratio and chi square analysis. For continuous variables, Pearson's r correlation was used, and t tests were used to test the difference between means in two groups.

Multivariate analyses were used to assess interaction effects and the relative contribution of each predictor variable to the outcome variable. Multiple regression, logistic regression, and analysis of variance were used. In some cases, data were stratified as described above and contingency table analyses were done to assess the modification of the relationship between the predictor and outcome variables.

More specifically, the statistical relationship between water quality measures and Body Mass Index were analyzed.

IRB Approval

This study was approved by the Baylor University Institutional Review Board before data collection began. All data from human subjects was anonymous. Informed consent was obtained before a subject provided data for the study.

CHAPTER FIVE

Results

Sample Characteristics

Data were collected between May 19 and June 3, 2013. The sample consisted of 179 children under the age of 18, with 47% boys and 53% girls. The average subject age was 5.38 years (SD=4.18) and ranged from 0 to 17 years. There was no significant difference in age between males and females (p=0.47).

The outcome variables in this study were Body Mass Index (BMI) and Body Mass Index Z-score. Table 5-1 shows the outcomes for BMI and z-scores for the total sample. There was no significant difference in BMI based on gender or education (see Table 5-2).

Table 5-1: Sample BMI Values

Outcome Variable	Mean (SD)	Range
Body Mass Index	17.09 (3.79)	11.79-35.98
BMI Z-score	-0.09 (1.39)	-3.79-2.98

*Values >4 SD below or >3 SD above the mean were excluded.

Head-of-household education data were collected and are summarized in Table 5-2. Most notably, table shows that approximately one in four children have caretakers who report having no education, and another two-thirds of the adults only have primary education, leaving 11% of the sample with secondary education or above.

Table 5-2: Outcome Variables, Gender and Education

Variable	BMI					BMI Z-SCORE			
	Percentage (n)	Mean (SD)	Range	t/F	p	Mean (SD)	Range	t/F	p
GENDER									
Boys	47.27% (78)	16.80 (3.47)	13.21-35.20	0.76/ 1.35	0.45	-0.17 (1.35)	-5.78	0.57/ 1.14	0.57
Girls	52.73% (87)	17.34 (4.04)	11.79-35.98			-0.02 (1.44)	-6.76		
EDUCA-TION				R^2				R^2	
None	23.26% (40)	16.20 (3.02)	12.77-25.19	0.01	0.45	-0.51 (1.31)	-5.17	0.02	0.28
Primary	65.70% (113)	17.41 (4.29)	11.79-35.98			-0.05 (1.46)	-6.77		
Secondary+	11.05% (19)	17.03 (2.41)	14.09-21.88			0.19 (1.08)	-4.25		

Environmental Quality Variables.

Self-report data were collected describing the living conditions and environmental challenges faced by the subjects in the sample. One factor was whether or not the household had a pit latrine or whether people simply used “the bush.” Homes do not have chimneys, and many people in this region cook indoors over open wood fires. However, some households do cook outdoors. Higher-quality housing decreases exposure to dirt, rain, and pathogens. Houses were categorized as poor if they had dirt floors, thatched roofs, no windows, and mud walls. Environmental factors also included whether the child slept on a dirt floor (as opposed to concrete or in a bed) and whether or not they slept under a mosquito net. Tables 5-3 and 5-4 show the frequencies of these conditions among the sample. The utter poverty of this sample is seen in the fact that, except for sleeping under a mosquito net, at least two-thirds of the children were in the worst conditions. Tables 5-3 and 5-4 also show that there were no significant differences in BMI based on any of these variables when they were tested individually, with the exception of the relationship between cooking location and BMI Z-score (discussed later).

Table 5-3: BMI and Environmental Variables

Variable	FREQUENCY	BMI			
	Percentage (n)	Mean (SD)	Range	t	p
TOILET					
None	75.95% (120)	17.15 (3.60)	12.76-35.98	0.54	0.59
Pit Latrine	24.05% (38)	16.61 (2.16)	13.92-20.85		
COOKING					
Inside	72.63% (130)	16.99 (4.23)	11.78-35.98	-0.48	0.63
Outside	27.37% (49)	17.35 (2.54)	13.34-24.21		
MOSQUITO NET					
No	40.78% (73)	16.96 (3.97)	11.97-35.98	-0.37	0.71
Yes	59.22% (106)	17.23 (3.64)	13.07-35.19		
HOUSING					
Poor	65.36% (117)	17.40 (4.26)	11.78-35.98	1.28	0.20
Good	34.64% (62)	16.41 (2.31)	13.07-21.87		
SLEEP					
Dirt floor	65.92% (118)	17.16 (3.78)	11.79-35.20	0.27	0.79
Concrete or Bed	34.08% (61)	16.96 (3.86)	12.77-35.98		

Table 5-4: BMI Z-score and Environmental Variables

Variable	FREQUENCY	BMI Z-SCORE			
	Percentage (n)	Mean (SD)	Range	t	p
TOILET					
None	75.95% (120)	-0.03 (1.36)	-6.27	0.00	1.00
Pit Latrine	24.05% (38)	-0.03 (1.40)	-5.08		
COOKING					
Inside	72.63% (130)	-0.24 (1.46)	-6.76	-2.07	0.04
Outside	27.37% (49)	0.27 (1.17)	-4.87		
MOSQUITO NET					
No	40.78% (73)	-0.27 (1.40)	-6.76	-1.35	0.18
Yes	59.22% (106)	0.08 (1.37)	-5.97		
HOUSING					
Poor	65.36% (117)	-0.06 (1.40)	-6.76	0.28	0.78
Good	34.64% (62)	-0.14 (1.40)	-5.69		
SLEEP					
Dirt floor	65.92% (118)	-0.07 (1.40)	-6.71	0.18	0.86
Concrete or Bed	34.08% (61)	-0.12 (1.41)	-6.27		

Health Status Variables.

Subject health information is summarized in Tables 5-5 and 5-6, which also indicate that there were no significant differences in BMI based on these conditions. Malaria was the most prevalent problem for the sample, with more than half having experienced at least one episode in the past year and 13.12% (n=21) having had more than three episodes in the last year. Two cases of HIV were reported, but because of lack of testing and hesitancy to reveal HIV status, this figure may be lower than the actual prevalence. Diarrhea was reported less frequently than expected, with 17.26% reporting that the subject had experienced at least one episode of diarrhea within the last three months. It is likely that this estimate is also low. Family sizes are large, and it may be difficult for the adult to remember this health outcome for a particular child. Also, given the frequency of infection and poor nutrition, runny stools may be considered a normal occurrence.

Table 5-5: BMI and Health Status Variables

Variable	OVERALL FREQUENCY	BMI			
	Percentage (n)*	Mean (SD)	Range	t	p
MALARIA					
No	32.50% (52)	17.42 (4.50)	11.79-35.20	0.78	0.44
Yes	67.50% (108)	16.84 (2.84)	12.77-25.19		
DIARRHEA					
No	82.74% (139)	16.84 (3.50)	11.79-35.20	-0.03	0.98
Yes	17.26 (29)	16.87 (2.35)	13.92-20.85		
HIV				F	
No	58.97% (92)	16.15 (2.49)	12.77-25.19	1.96	0.15
Yes	1.28% (2)	16.71 (1.96)	15.32-18.10		
Don't Know	39.74% (62)	17.50 (4.21)	11.79-35.20		

*Data do not add to 100% due to rounding.

Table 5-6: BMI Z-score and Health Status Variables

Variable	FREQUENCY	BMI Z-SCORE			
	Percentage (n)*	Mean (SD)	Range	t	p
MALARIA					
No	32.50% (52)	-0.26 (1.35)	-6.51	-0.99	0.32
Yes	67.50% (108)	0.04 (1.36)	-6.21		
DIARRHEA					
No	82.74% (139)	-0.19 (1.39)	-6.89	-0.94	0.35
Yes	17.26 (29)	0.19 (1.46)	-5.08		
HIV				F	
No	58.97% (92)	-0.30 (1.30)	-3.29-2.64	0.23	0.79
Yes	1.28% (2)	-0.36 (0.10)	-0.43- -0.29		
Don't Know	39.74% (62)	-0.11 (1.50)	-3.79-2.92		

*Data do not add to 100% due to rounding.

Water Quality Variables.

Water tanks were present at the households of 53% (n=95) of the sample. The average number of users per water tank was 8.57, with a standard deviation of 3.75 and a range of 2 to 22. There were no significant differences in age (p= 0.43) or gender (p=0.28) between the group with tanks and the group without tanks.

Among children with access to water tanks, information was recorded about the duration of the tank water supply, the use of tank water for purposes other than drinking, and the practice of boiling water. There was no significant difference in BMI based on a bivariate analysis of these variables (see Tables 5-7 and 5-8).

Table 5-7: BMI and Water Quality Variables

Variable		FREQUENCY	BMI				
		Percentage (n)	Mean (SD)	Range	R^2	t/F	p
BOIL WATER							
Yes		62.45% (59)*	17.23 (3.93)	11.79-35.19		-0.29/1.13	0.77
No		38.54% (37)	17.48 (4.17)	12.77-35.98			
WATER QUALITY							
No Tank		46.93% (84)	17.07 (2.79)	13.35-25.19		-0.06/2.45	0.95
TANK		53.07% (95)	17.12 (4.36)	11.79-35.98			
	DURATION OF TANK WATER						
	<5 Months	85.71% (90)	16.57 (2.89)	11.79-25.19		-1.33/2.54	0.19
	>5 Months	14.29% (15)	17.68 (4.60)	13.47-35.98			
	USES OTHER THAN DRINKING						
	Cook	65.71% (69)	15.65 (5.76)	11.79-21.88	0.21	9.86	0.0005
	Food	8.57% (9)	17.76 (1.72)	11.78-35.98			
	Dishes	49.52% (52)	15.60 (2.19)	11.79-20.85			
	Clothes	31.43% (33)	16.37 (2.20)	13.47-20.85			

Table 5-7: BMI and Water Quality Variables

Variable		FREQUENCY	BMI z-score				
		Percentage (n)	Mean (SD)	Range	R^2	t/F	p
BOIL WATER							
Yes		62.45% (59)*	-0.02 (1.49)	-3.79-2.92		-0.29/1.34	0.77
No		38.54% (37)	0.07 (1.28)	-3.29-2.98			
WATER QUALITY							
No Tank		46.93% (84)	0.06 (1.25)	-2.59-2.92		0.93/1.41	0.36
TANK		53.07% (95)	-0.19 (1.48)	-3.79-2.97			
	DURATION OF TANK WATER						
	<5 Months	85.71% (90)	-0.22 (1.43)	-3.79-2.92		-1.40/1.17	0.17
	>5 Months	14.29% (15)	0.25 (1.32)	-2.24-2.98			
	USES OTHER THAN DRINKING						
	Cook	65.71% (69)	-0.60 (1.18)	-3.79-2.64	0.24	10.11	0.0001
	Food	8.57% (9)	0.96 (1.10)	-0.28-1.82			
	Dishes	49.52% (52)	-.61 (1.52)	-3.79-2.49			
	Clothes	31.43% (33)	0.10 (1.35)	-2.24-2.49			

*Data do not add to 100% due to rounding

Of the 105 children whose households either had direct access to or shared a tank with a neighbor, the vast majority (85.71%) did not have tank water for the entire dry season; only 14.29% had access to clean water for the entire dry season. When this information is combined with the other half of the sample who did not have tanks, only 8.37% of all of the study subjects had clean water throughout the dry season. Ground water was obtained from one of seventeen sources on the Plateau. Boiling water was reported by 62% of the total sample as a method sometimes used to purify water.

The usages of tank water for things other than drinking were cooking, washing food, washing dishes, and washing clothing. Two-thirds of the sample used tank water for cooking and washing clothing, and half of subjects also used it for washing dishes. Less than 10% used tank water to wash food.

Approximately one-third of the tank water sample fell into one of three groups (see Table 5-9): 1) water used only for drinking, 2) water used for 1-2 other uses, and 3) water used for 3 other uses.

Table 5-9: Distribution of Sample by Number of Non-Drinking Uses

Number of Uses	Percentage (n)*
0	34.29% (36)
1-2	34.29% (36)
3	31.43% (33)

*Data do not add to 100% due to rounding.

A composite water quality score was created that included the presence or absence of a tank, how long the tank water lasted, and the number of non-drinking uses of the tank water. An ordinal grouping of these characteristics formed categories from worst (Group 1) to best (Group 4). The distribution of subjects and the characteristics of each category are presented in Table 5-10.

Table 5-10: Presence and Duration of Tank Water Among Subjects

Group	Water Source	Duration	Number of Non-Drinking Uses	Percentage (n)*
1	Groundwater	n/a	n/a	44.76% (47)
2	Water Tank	<5 months	1 or 2 of 3	21.90% (23)
3	Water Tank	<5 months	3 of 3	19.04% (20)
4	Water Tank	>5 months	n/a	14.29% (15)

*Data do not add to 100% due to rounding.

Analytic Statistics

Hypothesis: After adjusting for age, gender, and education, the duration of the clean water supply will influence BMI in children more than boiling or non-drinking use.

Regression analyses were used to analyze the relative effects of duration, non-drinking use, and boiling on BMI. The results of these tests are given in Tables 5-11, 5-12, and 5-13.

Table 5-11: Tank Duration and BMI

Variable	BMI			BMI Z-SCORE		
	R^2	F	p	R^2	F	p
Age	0.12	7.28	0.01	0.003	0.18	0.72
Gender	0.00	0.28	0.60	0.07	3.03	0.10
Education	0.12	3.58	0.04	0.12	2.62	0.09
Diarrhea	0.04	2.51	0.13	0.05	2.30	0.14
Malaria	0.04	2.52	0.12	0.07	3.17	0.09
DURATION OF TANK WATER	0.30	3.52	0.01	0.22	1.87	0.14

Table 5-12: Boiling Water and BMI

Variable	BMI			BMI Z-SCORE		
	R^2	F	P	R^2	F	p
Age	0.12	9.80	0.02	0.002	0.18	0.67
Gender	0.02	1.32	0.26	0.004	0.36	0.55
Education	0.12	0.90	0.41	0.04	1.67	0.20
Diarrhea	0.04	0.00	0.99	0.001	0.14	0.71
Malaria	0.03	2.44	0.12	0.05	5.87	0.05
BOILING WATER	0.02	0.89	0.42	0.03	2.18	0.12

Table 5-13: Non-Drinking Use and BMI

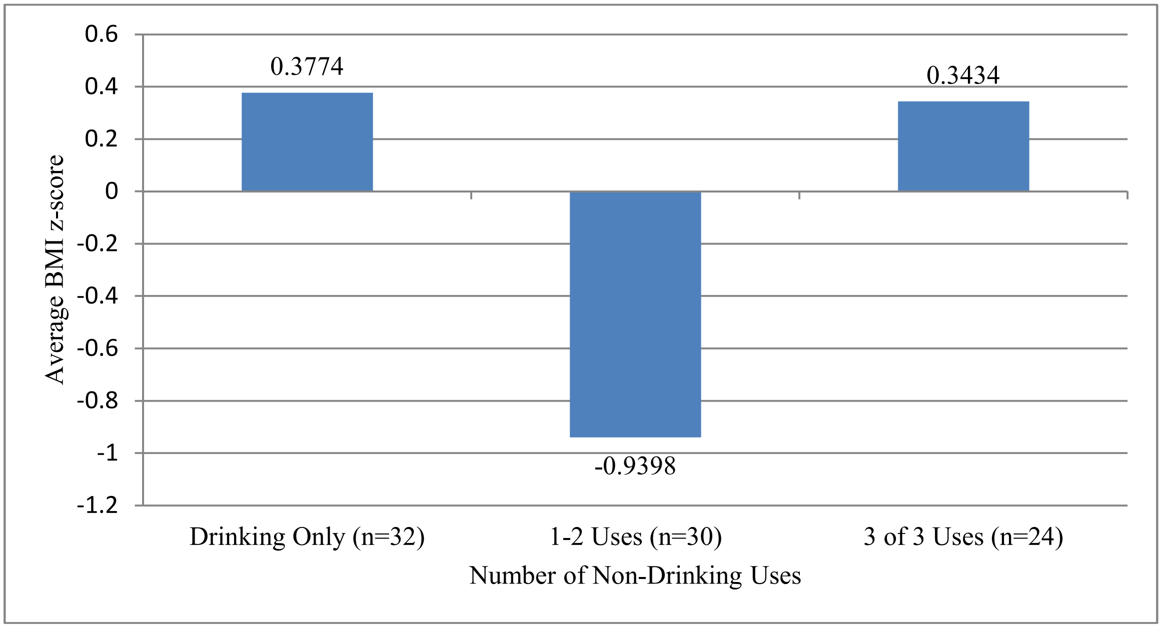
Variable	BMI			BMI Z-SCORE		
	R^2	F	P	R^2	F	p
Age	0.12	7.08	0.01	0.004	0.18	0.68
Gender	0.004	0.27	0.61	0.04	1.47	0.24
Education	0.12	3.49	0.05	0.12	2.57	0.10
Diarrhea	0.04	2.44	0.13	0.05	2.25	0.15
Malaria	0.04	2.52	0.13	0.05	3.1	0.09
Non-drinking use (tank)	0.24	6.80	0.005	0.14	2.86	0.08

According to these tables, the duration of the tank water supply had a significant effect on BMI but not on BMI z-score. Boiling water was not shown to significantly modify the relationship between water quality and BMI. Furthermore, non-drinking use of tank water significantly affected BMI and nearly significantly affected BMI z-score.

The effects of non-drinking usage of tank water (among subjects with tanks) were also evaluated using ANOVA. As shown in Table 5-13, non-drinking usage of tank water proved to be a significant modifier of BMI; however, the trend illustrated in Figure 5-1 indicates a surprising U-shaped curve that violated the theoretical expectation that BMI would increase with the number of non-drinking uses of tank water. This surprising trend warranted further analysis.

Several different methods were employed to attempt to explain the trend in Figure 5-5. First, BMI z-scores were regressed on the same variables with the addition of the duration variable. The model revealed a positive correlation between subject BMI z-scores and the duration of the tank water supply with an adjusted R^2 of 0.09 ($F=7.94$, $p=0.006$) compared a non-significant relationship in the previous model. The duration of tank water supply thus explained some of the variance in subject BMI and thereby became an important factor in explaining the unexpected trend in Figure 5-1.

Figure 5-1: BMI z-score vs. Number of Non-Drinking Uses



BMI was then regressed upon the duration of the tank water supply, stratifying by the number of non-drinking uses of tank water. The results of this test are displayed in Table 5-14.

Table 5-14: BMI z-scores Regressed on Duration of Tank Supply, Stratified by Number of Non-Drinking Uses

Number of Non-drinking Uses	Percentage (n)	R^2	F	p
Drinking Only	37.33% (28)	0.04	0.00	0.99
1 or 2 of 3	30.67% (23)	0.14	4.45	0.05
3 of 3	32.00% (24)	0.36	13.69	0.001

The results in Table 5-14 shed some light on the trend in Figure 5-1. The increasing values of R^2 with the number of non-drinking uses indicates that the duration of the tank water supply has a greater beneficial effect on growth as the water supply is used for more things. This makes logical sense, as one would expect that higher levels of exposure reduction (through a greater number of non-drinking uses of tank water) would be more beneficial over longer periods of time. While this finding explains the trend between groups 2 and 3, it also indicates that other confounders are at play within group 1.

Hypothesis: After adjusting for age, gender, education, and health status, children with access to clean drinking water will have BMI values no different than the control group.

According to Tables 5-7 and 5-8, there was no significant difference in BMI between the two groups. This supports the study hypothesis. However, after adjusting for other variables, a regression analysis showed that water quality did significantly impact BMI values. This is illustrated in Table 5-15 below.

Table 5-15: Water Quality and BMI, Adjusting for Other Variables

Variable	BMI			BMI Z-SCORE		
	R^2	F	p	R^2	F	p
Age	0.12	11.28	0.001	0.002	0.2	0.67
Gender	0.02	1.52	0.22	0.004	0.4	0.55
Education	0.06	2.68	0.08	0.08	3.43	0.03
Diarrhea	0.00	0.00	0.99	0.05	0.15	0.70
Malaria	0.10	2.80	0.10	0.05	4.25	0.04
WATER QUALITY (tank)	0.10	3.05	0.03	0.11	2.89	0.04

One might interpret these results as conflicting, but one interpretation of their coexistence as an indication that tank water actually promoted growth in children which then resulted in the equivalence in BMI between tank and non-tank subjects. There are several reasons why one might interpret this result as such. Firstly, water tanks were given to the poorest people in the area—people whose living conditions were worst and likely hindered growth. When the negative effects of certain environmental variables are ignored, BMI z-scores increase with water quality. If the tank subjects indeed had lower BMI's before the installation of the water tanks, then the fact that there is no significant difference in BMI between tank and non-tank subjects seems to indicate that improving water quality improves growth.

The Non-Tank Advantage. The assumption that tanks were given to the poorest households was supported by the data. Table 5-16 shows that subjects in non-tank households were at a significantly lower risk for several exposures compared to subjects in tank households. Subjects without water tanks were less likely to sleep on a dirt floor (p=0.03) and were more likely to sleep under a mosquito net (p=0.001) and cook outside (p=0.003).

Table 5-16: Pre-Intervention Advantages of Non-Tank Subjects

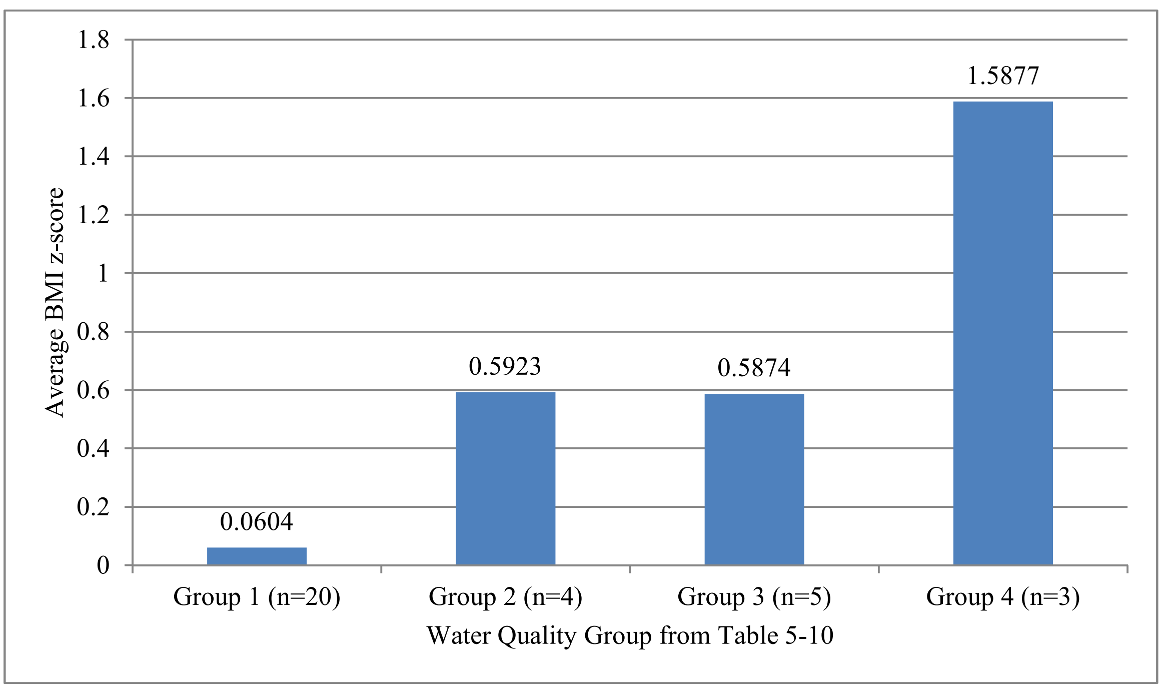
Variable	RR	χ^2	p
Not Sleeping on a Dirt Floor (n=156)	2.11	4.31	0.03
Mosquito Net Use (n=179)	2.22	6.38	0.001
Cooking Outside (n=179)	1.54	8.86	0.003

The higher rate of outdoor cooking among non-tank subjects is especially important given the significantly higher BMI z-scores of subjects who cook outside (see Table 5-4).

Given that the better-off, non-tank group had a higher prevalence of subjects sleeping under mosquito nets and living in homes were cooking took place outside (and that those who lived these homes had higher average BMI z-scores), the model was then stratified by cooking location to remove the potential effects of confounding by net use cooking location. ANOVA was used to compare the average BMI z-scores of subjects sleeping under mosquito nets and living in homes where cooking was done outdoors in the four groups defined in Table 5-8.

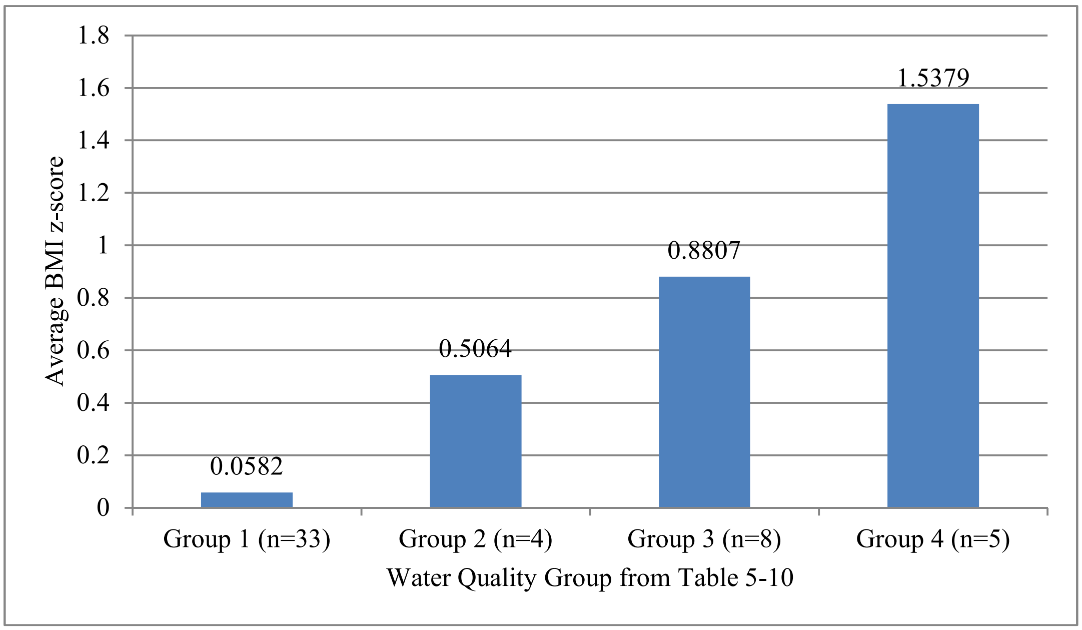
The results for the four groups are given in Figures 5-2 and 5-3. It is important to note that the average BMI z-score of the groundwater group was lower when cooking location was adjusted for. The trend in Figure 5-3 was consistent with theoretical expectations in that, once the effects of cooking indoors were removed, water had the expected effect on growth.

Figure 5-2: BMI z-score vs. Water Quality Among Subjects in Outdoor-Cooking Households



When stratifying by net use, the same trend found in Figure 5-2 was found in Figure 5-3: among subjects in healthier environments (net users), there was a positive relationship between water quality and BMI.   While the model was not significant (p=0.07), it would likely be significant given a larger sample size.

Figure 5-3: BMI z-score vs. Water Quality Among Mosquito Net Users



The next step was to simultaneously adjust for both cooking location and net usage, given that stratifying by each of these individually revealed similar trends in BMI z-score for water quality. A t-test was performed to compare the average BMI z-scores between subjects who neither cooked outside nor slept under a net ("Environment"=Poor) versus subjects who either cooked outside or slept under a net ("Environment"=Better). These results are given in Table 5-17.

The results in Table 5-17 demonstrate the combined protective effects of the use of mosquito nets and the practice of cooking outdoors, as evidenced by the significantly higher average BMI z-score of subjects in the group participating in one or both of these practices.

Table 5-17: Protective Variable Effects on BMI Z-scores

Group	Percentage (n)	Mean (SD)	Range	t	p
Neither Net Use nor Outdoor Cooking	35.21% (50)	-0.43 (1.29)	-3.79-2.97	-2.62	0.01
Net Use and/or Outdoor Cooking	64.79% (92)	0.19 (1.38)	-3.05-2.92		

Using multiple linear regression, BMI z-scores were regressed on water quality, environment, and sex. The model generated an R^2 of 0.24 (p=0.0007), showing that, when adjusting for environmental factors and sex, there is a relationship between water quality and BMI z-score. Within the model, environment and water quality (as defined by Table 5-10) were significant. Sex was almost significant. These results are presented in Table 5-18.

Table 5-18: BMI z-scores Regressed on (n=82):

Variable	R^2	F	p
Water Quality	0.10	3.49	0.0014
Environment	0.11	10.97	0.0198
Sex	0.03	2.81	0.0981
Overall:	0.24	4.85	0.0007

In order to better understand the effect of gender as it modifies these relationships, BMI z-scores were regressed on water quality and environment and then stratified by gender. Among males, there was no significant relationship between the variables (see Table 5-19).

Table 5-19: Among Males (n=35) BMI z-scores Regressed on:

Variable	R^2	F	p
Water Quality	0.04	0.70	0.5599
Environment	0.06	1.36	0.2532
Overall:	0.10	0.86	0.4970

However, among girls (n=47), an even more significant model (see Table 5-20) was obtained (R^2=0.47 compared to R^2=0.24). Protective environmental factors and water quality contribute to an explained variance of 0.47, compared to the R^2 of 0.24 in the previous model that included both boys and girls. Thus, among girls, when adjusting for environmental variables, there is a significant relationship between water quality and average BMI z-score.

Table 5-20: Among Females (n=47) BMI z-scores Regressed on

Variable	R^2	F	p
Water Quality	0.21	6.82	0.0002
Environment	0.26	16.49	0.0008
Overall:	0.47	9.24	<0.0001

Hypothesis: After adjusting for age, gender, and health status, measures of a better environment will be associated with a higher BMI in children.

A t-test was performed to compare average between a group of subjects living in homes practicing indoor cooking (n=79) and subjects living in homes practicing outdoor cooking (n=35); the results are summarized in Table 5-3 and Table 5-4.

The results in Tables 5-3 and 5-4 indicate that subjects living in households practicing outdoor cooking have a higher average BMI z-score than subjects living in households practicing indoor cooking. As previously mentioned, no other significant relationships were found between environmental variables and BMI.

Hypothesis: After adjusting for age, gender, and environmental variables, poor health outcomes are associated with a lower BMI in children.

To ascertain whether or not malaria had an impact on growth, a t-test was performed to compare average BMI between a group of subjects reported to not have had malaria in the past year (n=52) and subjects who were reported having had malaria in the past year (n=108). The results of this test are given in Tables 5-5 and 5-6, which show that there is no statistically significant relationship between malaria and BMI in the study.

To explore diarrhea's effects on growth, a t test was performed to compare the average BMI z-scores of subjects who had (n=29) and had not (n=139) reported experiencing diarrhea over the past three months. According Tables 5-5 and 5-6, there is no significant relationship between diarrhea and BMI.

Hypothesis: After adjusting for age, gender, and environmental factors, better water quality will be associated with better health outcomes in children.

To analyze the effects of water quality on diarrhea, Chi-square tests were performed. The results of these tests are given in Table 5-21.

Table 5-21: Water Variable Effects on Diarrhea Outcomes

Variable	Stratification	RR	χ^2	P
Water Tank Presence (n=146)		2.04	2.58	0.112
Non-drinking Usage of Tank Water (n=87)	Drinking Only (n=26)	1.00	3.44	0.18
	1-2 of 3 Uses (n=28)	0.34		
	3 of 3 Uses (n=33)	1.01		
Duration of Tank Supply (n=87)		0.52	0.58	0.45

Table 5-21 indicates that there is no significant relationship between water variables and diarrhea.

Hypothesis: After adjusting for age, gender, and environmental factors, better environmental conditions will be associated with better health outcomes in children.

A subject's use of a mosquito net was theoretically expected to affect his malaria status. A Chi-square test was performed to compare malaria incidence between those who slept under mosquito nets (n=97) and those who did not sleep under mosquito nets (n=63). A subjects use of a mosquito net was nearly significantly (p=0.12) protective (RR=0.58) against malaria. Given a larger sample size, a statistically significant model might be obtained.

Factors hypothesized to affect diarrhea were sleeping on a dirt floor (as opposed to a concrete floor or a bed) and poor housing construction. Chi-square tests were performed to evaluate these effects, and the results of these tests are given in Table 5-22. Surprisingly, a sleeping on a dirt floor was nearly significantly protective against diarrhea. This phenomenon warrants further investigation, especially given that poor house construction, which often encompasses a dirt floor, was even more closely (though still non-significantly) associated with increased diarrhea incidence.

Table 5-22: Diarrhea and Environmental Variables

Variable	RR	χ^2	p
Sleeping on Dirt Floor (n=168)	0.48	3.16	0.08
Poor House Construction (n=168)	2.10	3.31	0.07

Rainwater Collection Tanks and Malaria

A Chi-square test was used to compare the incidence of malaria between non-tank subjects (n=63) and subjects with water tanks (n=83). This relationship is especially important to look at, as the literature points out that rainwater collection tanks—intended to *improve* the health of their users—can be a standing water source in which mosquitoes can lay their eggs and thus potentially introduce more malaria into the community. Table 5-23 reassuringly indicates that there is no significant relationship between malaria and the presence of a water tank, and, among tank users, that there is no significant relationship between malaria and the number of non-drinking uses of tank water. The table reassuringly indicates that there is no significant relationship between malaria and the presence of a water tank, and, among tank users, that there is no significant relationship between malaria and the number of non-drinking uses of tank water.

Table 5-23: Water Variable Effects on Malaria Outcomes

<table>
<tr><th>Variable</th><th>Stratification</th><th>χ^2</th><th>p</th></tr>
<tr><td>Water Tank Presence (n=146)</td><td></td><td>1.24</td><td>0.27</td></tr>
<tr><td rowspan="3">Non-Drinking Usage of Tank Water (n=87)</td><td>Drinking Only (n=26)</td><td rowspan="3">1.93</td><td rowspan="3">0.38</td></tr>
<tr><td>1-2 of 3 Uses (n=28)</td></tr>
<tr><td>3 of 3 Uses (n=33)</td></tr>
<tr><td>Duration of Tank Supply (n=87)</td><td></td><td>0.58</td><td>0.45</td></tr>
</table>

CHAPTER SIX

Discussion

Significance

The results of the present study are significant in several respects. As community-based research, these findings are valuable to the particular organization that provided the tanks, because the study provides information about how this strategy is working on the Nyakach Plateau for the local population. The results are valuable to the inhabitants of the Nyakach Plateau in providing specific ways to increase their quality of life. Finally, this study provides information that is generalizable to the underserved population of the world. Millions of dollars have been invested in unsuccessful drilling or maintenance of water wells. The relatively inexpensive intervention investigated in the present study can be implemented in virtually all other areas lacking water infrastructure.

In the above context, the findings of the study represent several pieces of good news. When the water tanks were installed at the homes of the poorest people in the community, the hope of the research team was that access to clean water would help poorer children achieve growth similar to that of children living in safer, more advantageous environments. The fact that there was no difference in BMI between children with tanks and those without tanks after eight months of tank usage suggests that this was indeed the case. The limits of a cross-sectional study make it impossible to know for sure that these children were, in fact, smaller to begin with than their counterparts. However, the person who chose which homes received tanks is someone who has lived in the community, known the people his whole life, and devoted all of his own personal resources to helping only the very poorest children living on the Nyakach Plateau. This assumption was validated by the study's findings that the homes with tanks also had fewer mosquito nets and poorer home construction.

The finding that the children with tank water had presumably "caught up" with their neighbors was consistent with the literature, meaning that access to harvested rainwater reduces a child's exposure to many of the pathogens present in the contaminated groundwater in the area. This change can lead to significantly reduced morbidity from diarrhea, anemia, and other health risks. In turn, this reduced morbidity can help households save money (by reduced expenditure on medicines and clinic expenses) and divert it to education or food. Access to clean water could thus help an individual break the cycle of poverty that traps so many millions of people. This finding shows that this intervention definitely benefits the population on the Nyakach Plateau and will hopefully serve as an impetus for the installation of additional water tanks in the area.

But the significance of the study lies not just in documenting that rainwater harvesting is effective in this context: it also provides guidance as to how these tanks can be used to maximally impact health. It was unknown if using rainwater for things other than drinking, such as washing and cooking food using tank water instead of groundwater, would reduce disease exposure enough to impact children's growth even more. The fact subjects using tank water for non-drinking purposes were actually better off than their peers who only used the tank for drinking water is a finding with great practical significance. It is logical that the longer the rainwater is available, the better the outcome for the child. However, it was unknown if this was a difference that was large enough to be apparent in the relatively short period that this study monitored. The fact that those who had used the water longer had a higher BMI than others is a specific confirmation of the overall finding. The usefulness of these findings can be maximized through educating the population of the Nyakach Plateau on "best practices" of water use. The findings are additionally important because they provide concrete evidence for potential donors and funding agencies that more tanks are desperately needed for this community. Though people who have tanks are the poorest of very poor, they share their water with their neighbors; it is thus likely to be gone before the dry season is over.

The results of the study are especially significant to one group of people in particular: young girls. Globally one of the most underserved and underprivileged demographics, young girls in less-developed countries have even fewer opportunities to receive education or work and break the cycle of poverty than their male counterparts. The fact that water quality contributed to their growth was predicted by the literature; the fact that, among girls in the study, water quality was responsible for nearly *half* of the variance in female BMI is unprecedented.

A significant worry at the beginning of the tank installations was that this new water source would bolster this aspect of community health at the expense of increased malaria incidence. These tanks are, after all, large bodies of standing water—a perfect environment for mosquito larvae. As discussed earlier, the literature did show a number of cases in which similar interventions resulted in increased malaria incidence. The fact that this was not observed in the present study reflects how beneficial this intervention is. The inhabitants of the Nyakach Plateau can now have access to safe water without the anticipated risks; Straw to Bread can continue its installation of water tanks without simultaneously creating a worse problem. Not only was there a lack of association between malaria and tank water usage, but the occurrence of malaria also did not increase with a longer duration of the tank water supply. These reassuring findings show that this particular approach to maximizing water availability will not have the unintended consequence of increasing malaria in the community.

The findings of the study are not just important with respect to water quality. The fact that the effects of water quality on growth were greater when subjects slept under a mosquito net or cooked outdoors is significant for a number of reasons. First, this finding—in conjunction with the fact that nets protect from mosquitoes—provides justification for a multifaceted approach to improving the health of the people on the Nyakach Plateau. It also shows that another one of Straw to Bread's interventions, providing mosquito nets, has positively affected the health of the community. This finding also provides additional points on which the community on the Plateau can be educated. By looking for ways to enable the community to cook outdoors and to use their mosquito nets consistently, substantial morbidity due to respiratory illness and malaria may be avoided. By putting individuals at a reduced risk for illness, interventions such as these ultimately bring the members of the community one step closer to breaking the cycle of poverty.

Limitations

Cross-Sectional Design.

Correlation cannot prove causation, and cross-sectional studies such as the present one are subject to this limitation. In this case, a longitudinal study would have substantially more explanatory power. However, a cross-sectional study is only a first step, and subsequent studies could be conducted with the sample of the present study to analyze longitudinal trends.

Random Error

Perhaps one of the main factors contributing to the failure of the study to confirm some of the predicted relationships is sample size. Given the limited window of time during which data could be collected, obtaining a larger sample size was not feasible. With a larger sample size and a clearer picture of the relationships between many of the variables in the study, the relationship between water quality and growth in children would likely be better understood.

Systematic Error

Potential Confounding or Modification by Nutrition and Food Insecurity. Prior to the study, it was assumed that the people of the region were so homogenously poor that poor nutritional status and food insecurity would be uniform throughout the sample. In order to test this assumption, the parents of the children in this study were also questioned about the diet of their children, and this is the subject of a related, forthcoming study.

This information will be helpful in either documenting a consistent poor nutritional context into which the water intervention was made, or variation in diet and amount of food will be a factor that can inform the present study in important ways. It will be possible to study whether better nutrition has an independent, modifying, or non-significant impact on outcome relative to providing clean water.

Potential Response Bias and Recall Bias

Data Acquired by Self-Report. Aside from the anthropometric measurements used to calculate Body Mass Index, all of the data in this study were collected via self-report from the head of each household. This presents a potential for error in a number of ways. Firstly, the sensitive nature of much of the data, especially those concerning HIV status or diarrhea, could have led subjects to provide false information to avoid shame or embarrassment. Secondly, many variables about which data were collected required subjects to recall information from times not in the immediate past—i.e. the number of diarrhea episodes in the past three months or malaria episodes in the past year—for all of the children in a home. It is possible that the heads-of-household, with or without intention, reported incorrect data. As there is no way to verify with absolute certainty the accuracy of the data collected via self-report in the study, there is a degree of uncertainty about its results. However, it is likely that if the data were reported incorrectly, the errors would be consistently in the same direction. If this is true, then systematic error may have actually decreased the true effect, and the results seen in the study would have underestimated the impact of tank water on children's growth.

Construct Validity

The native language in the study area is Luo. While primary and secondary schools in the area teach English, the vast majority of subjects from whom data were collected had little, if any, English-speaking ability. The research team hired translators fluent in Luo, English, and Swahili to overcome this obstacle. While the translators greatly facilitated communication between investigators and subjects, a language barrier was still present, as the translators' native language was also not English. Because of the syntactic and cultural differences between English and Luo, not all words and phrases in one language had direct analogues in the other. The possibility thus arose for systematic error, in which translational errors could have consistently produced incorrect answers to certain questions.

There is a possibility that the way in which many of the variables were measured and operationalized was not valid. Diarrhea and malaria were assessed by determining whether or not subjects had experienced either in the past three months or the past year, respectively. This measurement does not adequately account for the potential of these conditions to affect subjects when experienced chronically rather than episodically; this is possibly the reason why diarrhea and malaria were not observed to have significant effects on growth in the study.

The way in which water quality was simply the use or lack of use of rainwater collected in tanks. There are many variables—including pathogen content, turbidity, and pH—that affect water quality, and these factors may have differed from tank to tank and from one groundwater source to another. A quantified measure of the actual quality of each water source would give much more precise information and would identify the degree of variability that is present.

Construct invalidity may also be an issue for the environmental variables measured in the study. This is so because certain variables, like sleeping environment and house construction, were predicted to have an effect on growth but did not. It is possible that more effective measures of environmental quality exist and might have been shown to affect growth. Because of the large amount of time subjects spend outdoors, it is likely that environmental quality was inappropriately assessed in the study.

In spite of these limitations, it is unlikely that the effects of water quality on growth in girls were observed in error, especially since the final model was statistically significant at the 0.0001 level. The lack of a relationship between water quality and growth in boys is an intriguing finding that may be strictly due to methodological limitations, or it may reflect a difference in exposure between boys and girls that can be explored in future studies.

Conclusion

The results of this study are important both to the Luo people on the Nyakach Plateau and to the impoverished population of the world in other places with scarce water and few resources to acquire it. The fact that the installation of rainwater collection tanks, rather than introduce malaria into the community on the Plateau, contributed positively to growth of children gives assurance that this intervention is truly beneficial and provides information about future strategies. Other impoverished rural communities could benefit from the installation of these tanks now that their efficacy is documented.

Ultimately, the acquisition of clean drinking water by the world's rural poor brings them one step closer to breaking the vicious cycle of poverty in which they are ensnared.

Further Research

Many of the results of the study raise questions that should be answered by further research. Most urgently, it is important to understand why water quality had an effect on growth in girls but not in boys. If this observation was not made due to random or systematic error, other interventions are necessary for boys to achieve better growth. Secondly, the results of the study necessitate an intervention to educate the study population as to the most effective use of tank water. Because of translational and other issues, it is likely that several different methods will have to be evaluated. A follow-up study can then be conducted to assess the efficacy of this educational intervention in promoting growth in the study population.

APPENDIX

APPENDIX I: WATER QUALITY QUESTIONNAIRE

1. PID: _______________________

2. Do you have a water tank at your home?
___Yes (1) ___No (0)

a. If no, do you share one with a neighbor?
___Yes (1) ___No (0)

3. How many people take water from the tank? ___________

4. Is the tank covered?
___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

5. Do you uncover your tank when it is raining?
___Yes (1) ___No (0)

6. Have you noticed mosquitoes in, on, or around the tank?
___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

7. Does the water in your tank last you the whole dry season?
___Yes (1) ___No (0)

a. If not, for how many months of the dry season are you able to obtain water from the tank? _______ mos.

8. Do you have a water filter?
___Yes (1) ___No (0)

9. If yes, how often do you use the water filter?
___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

10. Do you use any water safety methods other than a tank or filter, like sanitation tablets or solar disinfecting?
___Yes (1) ___No (0)

11. Do you use **tank water**:
a. To cook?
___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)
b. To water crops/food you grow?
___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)

___Never? (0)

c. To clean dishes?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

d. To wash clothes?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

e. To drink?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

12. Do you use **filtered water**:

a. To cook?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

b. To water crops/food you grow?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

c. To clean dishes?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

d. To wash clothes?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

e. To drink?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

13. Do you use **groundwater**:

a. To cook?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

b. To water crops/food you grow?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

c. To clean dishes?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)

___Never? (0)

d. To wash clothes?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

e. To drink?

___All of the time? (1)
___Most of the time? (2)
___Less than half of the time? (3)
___Never? (0)

COMMUNITY HEALTH ASSESSMENT PROFILE (CHAP)—General Questions

1-PID______________________ (2,3,4)-Date____/____/____ (mo/dy/yr)

(5,6,7)-Date of Birth____/____/____ (mo/dy/yr) 8-Age: ________yrs

Malaria
11-Number of times since S2B last visit (May 2012): _______ times
12-Take medicine to treat it?
____ N/A(99)
____ Yes(1)
____ No(2)
13-Time since last episode:
_______have not had it
_______ wks ago
_______I have it right now

14-Does patient have HIV?
____Yes(1) ___No(0)
____Don't know(99)

15-When diagnosed? ____N/A(99)
___yrs (proportion of year if <1 yr)
15a-When last tested? mo/dy/yr
or ___N/A (99)
16-Treatment now?
___yes(1) ____No(0) ___N/A(99)
17-How long? ____N/A(99)
___yrs (proportion of year if <1 yr)

18-Have you (or your child, if child is the subject) experienced diarrhea (more loose or liquid stools in one day than is usual) within the past:
19a. week? Y [1] N[0]
If so, how many days? _________
19b. month? Y[1] N[0]
If so, how many days?_________
19c. three months? Y[1] N[0]
If so, how many days?_________
19-Last time treated for worms :
___months ago ___not treated(99)

26-Still enrolled in school? ____No(0) ____Yes(1)
27-How much school completed?
_____adult, but never went to school(0)
_____primary(1)
_____secondary or trade school(2)
_____university(3)
_____too young for school(4)

37-What kind of toilet facilities do you use when you are at home?
____none, go in the bush(0)
____community latrine(1)
____open pit latrine(2)
____closed pit latrine(3)
____flush to piped sewer system(4)

39-House questions
a. Roof:
__thatch(1) __metal(2) __tile(3)
b. Wall:
__mud/dung(1) __brick(2) __metal(3)
c. Floor :
__dirt/dung(1) __concrete(2) __tile(3)
d. Windows:
____ none(0)
____ glass(1)
____ curtains, but no glass(2)
____ open with no closure(3)
d. Cooking:
____inside open wood fire(1)
____outside open wood fire(2)
____inside stove(3)
____none(0)
e. Where does pt sleep:
____dirt floor(1)
____concrete floor(2)
____bed(3)
40-Do you usually sleep under a mosquito net? ____Yes(1) ____No(0)

41-What is the ONE **main** source of drinking water for pt's household?

a. Type
_____ ground water(1)
_____ Tank(2)
_____ Tank + filter(3)
_____ Filtered ground water(4)
_____ rainwater caught in buckets(5)

b. Location (if applicable)
Location: _______________
Location: _______________
Location: _______________
Location: _______________

1-ID AND SEX: ______________________________

2-DOB: (m/d/yr) _____________________

3-Ht (cm)	
4-Wt (kg)	
5-MUAC (cm)	
6-Waist (cm)	
7-Head (if under 2, cm)	

1-ID AND SEX: ______________________________

2-DOB: (m/d/yr) _____________________

3-Ht (cm)	
4-Wt (kg)	
5-MUAC (cm)	
6-Waist (cm)	
7-Head (if under 2, cm)	

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