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A Survey of Water Storage Practices and Beliefs in Households in Bonao, Dominican Republic in 2005

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Abstract

Shelley Holt

A survey of water storage practices and beliefs in households in Bonao, Dominican Republic in 2005 (Under the direction of Christine Stauber, Faculty Member)

INTRODUCTION: More than 2.2 million people die each year from diarrheal disease. Most cases of diarrheal disease can be linked with a lack of access to clean water and sanitation. The proper usage of sanitation, hygiene and safe drinking water are all mechanisms by which to prevent or limit fecal contamination, and in turn, reduce the risk of diarrheal disease. As a result, it is imperative to examine and understand risk factors for fecal contamination of drinking water in the home. One way to assess fecal contamination is to use indicator bacteria such as *E. coli*. These bacteria can be easily measured and have been weakly associated with increased risk of gastrointestinal illness.

PURPOSE: The purpose of this study was to determine if characteristics of household drinking water storage containers impacted the concentration of total coliforms and *E. coli* in the stored household drinking water in rural Dominican Republic communities.

METHODS: The data were collected through a cross-sectional survey and from a four month prospective cohort study in rural communities in the Dominican Republic during 2005. Data analysis was conducted using STATA 10. Descriptive statistics were calculated and reported as percentages. Bivariate statistics were carried out to test independent associations between container characteristics and *E. coli*. In addition, t-tests were used to examine differences in concentrations of *E. coli* and total coliforms as well as other household and water characteristics that may play an important role in household drinking water management and practice and contamination.

RESULTS: After testing independent potential risk factors for *E. coli* contamination, it was determined that household storage practices have a significant impact on drinking water quality. More specifically, households that stored drinking water in containers with narrow openings (typically < 2 inches in diameter) had lower concentrations of *E. coli*. The water was more likely to remain protected from additional contamination once stored in the home.

DISCUSSION: The association with household storage practices with *E. coli* contamination reveals the importance of point of drinking water management in the home. Specifically, we documented simple storage practices (commonly practiced in homes in the Dominican Republic) that can protect or reduce drinking water from contamination once in the home. While previous literature has been unable to identify a single most important risk factor of *E. coli* contamination in drinking water, findings from this study and previous studies indicate that more research is needed to further elucidate the role of household drinking water storage techniques in protecting household members and reducing risk of disease.

INDEX WORDS: water quality, *E. coli*, Dominican Republic, narrow-mouth, water storage

A SURVEY OF WATER STORAGE PRACTICES AND BELIEFS IN HOUSEHOLDS IN BONAO, DOMINICAN REPUBLIC IN 2005

By SHELLEY HOLT

BS BIOLOGY, MS BIOLOGY

A Thesis Submitted to the Graduate Faculty of Georgia State University in Partial Fulfillment of the Requirements for the Degree

Master of Public Health

Atlanta, GA 30303

A survey of water storage practices and beliefs in households in Bonao, Dominican Republic in 2005

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CHAPTER I: INTRODUCTION

1.1 Background

More than 2.2 million people die each year from diarrheal disease[1]. Most cases of diarrheal disease can be linked with a lack of access to clean water and sanitation[2-3]. The proper usage of sanitation, hygiene and safe drinking water are all mechanisms by which to prevent or limit fecal contamination, and in turn, will reduce the risk of diarrheal disease. *E. coli* is a bacterial indicator of fecal contamination that has been associated with increased risk of diarrheal disease[4]. Without access to protected water sources, there is greater potential for fecal contamination of drinking water. Many times, due to lack of infrastructure, -families in developing countries collect and store water -in the home, both for drinking and other household purposes._ In some cases, they treat the water themselves at the household level. Because water quality plays such an important role in the health of these communities, it is imperative to examine and understand risk factors for fecal contamination of drinking water in the home. These include household water management practices and beliefs regarding water collection and storage.

1.2 Purpose of Study

Often in developing countries water quality deterioration occurs after collection, and presents a public health risk to those consuming the water. As a result, there are advantages to understanding domestic water storage and management practices. Understanding these may aid in developing practical strategies for preserving drinking water quality until the point of consumption. The purpose of this project was to determine if characteristics of- household storage containers affect the concentration of *E. coli* in the stored household drinking water in rural Dominican Republic communities. The first objective was to analyze the bacteriological quality of water at the point of consumption and the household storage container. In addition, I examined whether personal hygiene beliefs and water handling practices have any correlation with *E. coli* concentrations in the stored water. Furthermore, I documented the normal weekly practices of collection and storage of drinking water to determine if they differ from the methods the participants originally reported in a preliminary interview.

1.3 Research Questions

The purpose of this study is to determine potential risk factors for *E. coli* contamination of household drinking water in Bonao, Dominican Republic. Determination of potential risk factors was assessed by answering the following questions:

1) Is fecal contamination of household drinking water affected by the characteristics of the container it is stored in?

2) Do household storage practices and beliefs affect *E. coli* levels in stored water?

CHAPTER II: REVIEW OF THE LITERATURE

Most studies examining water quality in less developed countries have focused on the prevalence of diarrheal disease and its association with contaminated water[5]. While this research is informative, it is important to determine potential risk factors for fecal contamination of drinking water such as household water management practices. This literature review will serve to examine the relationship between household drinking water collection, storage, contamination and documented health effects.

2.1 Access to water, sanitation and hygiene

The beginning of an era commenced in 2005 with the “International Decade for Action: Water for Life” and inspired the renewal of efforts to accomplish the Millennium Development Goals (MDGs). UNICEF and the WHO (World Health Organization) have estimated that 1.1 billion lack access to improved water supplies and 2.6 billion people lack adequate sanitation facilities[6]. Presently, key areas of research focus on the relationships between lack of access to water, sanitation and hygiene and the burden of disease in underdeveloped regions. Access to clean water, sanitation and hygiene are all critical components to health, survival and development, specifically among children under the age of five. Diarrheal diseases are largely due to lack of water, sanitation and hygiene. The category of “diarrheal disease” can include ailments such as cholera, typhoid and dysentery, all of which have a fecal-oral route of transmission. Worldwide 94% of diarrhea cases are attributed to reasonably modifiable environmental factors such as unsafe water, inadequate sanitation or insufficient hygiene[7].

Access worldwide

Around the world, access to improved water sources for drinking can be inadequate, and access to clean water is even more limited since improved access does not always guarantee safety. Unfortunately, 1.1 billion households do not have access to an improved water source[8], which is defined as one that, by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with fecal matter[9]. In Table 1 is a list of improved and unimproved water sources as determined by the Joint Monitoring Programme of the WHO and UNICEF.

Table 1: Examples of improved and unimproved water sources[9]

Drinking water source	
Improved	**Unimproved**
> Piped water into dwelling, plot or yard	> Unprotected dug well
> Public tap/standpipe	> Unprotected spring
> Tubewell / borehole	> Small cart with tank/drum
> Protected dug well	> Tanker truck
> Protected spring	> Bottled water *
> Rainwater	> Surface water (river, dam, lake, pond, stream, channel, irrigation channel)

[1]

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[1] Bottled water is considered to be improved only when the household uses water from another improved source for cooking and personal hygiene; where this information is not available, bottled water is classified on a case-by-case basis

A 2008 study has actually suggested that the condition of water supplies may not be favorable, even in areas that supposedly have access to better water sources[10]. This may be due to a variety of reasons, such as disagreements on the payment of operational costs after construction, poorly engineered boreholes, pressure loss, and damaged taps and pipes[11]. Other possible factors negatively affecting the quality of water being received through these "improved" sources include disputes about or difficulties purchasing the diesel needed to run the pump or to pay for routine maintenance and repair needed for the pump[10]. Over the past 15 years approximately 33% of waterborne outbreaks could be explained by examining problems with water dispersal[12]. Hunter *et al.* found that just one day of exposure to unimproved water because of supply failures has significant impacts on the annual risk of enterotoxic *E. coli* infection[11]. This risk continues to increase, and reaches a 99% risk of infection by 34 days of exposure to unimproved sources[11].

Notwithstanding problems associated with improved water supplies, one of the main targets of the United Nations' MDGs is to halve the number of people without sustainable access to improved drinking water and sanitation by 2015[13]. Between 1990 and 2006, the percentage of people with access to improved drinking water rose form 76% (4.1 billion) to 86% (5.7 billion). During the same time frame, around 1.1 billion people gained access to improved sanitation in developing regions[8]. Even if a sustainable water source is available, it is not necessarily going to be safe for consumption. For example, there are still 900 million people who must rely on water from readily available, but unimproved supplies such as surface water or a vulnerable, unprotected dugout well[8]. Along the same lines, a water source may be considered "improved" by WHO/UNICEF standards, but it does not mean that it is safe or free of contamination. Bottled water, for instance, is deemed improved when the household uses water from another improved source for cooking and personal hygiene[9]. Just because households have access to improved water sources does not mean that bottled water will be free of contamination or safe. One of the central focal points for the provision of safe water is the associated improvements to health. Estimates by the WHO indicate that by providing safe drinking water and improved sanitation conditions in developing countries, on average a household would gain 60 minutes per day in terms of time spent collecting, transporting, and treating their water[14]. This extra time could be spent focusing on learning about and improving overall health. Other key health gains aside from reduced diarrheal disease include reduced back strain and improved security as a result of decreased time spent traveling to water sources.

In addition to increasing access to improved water, hygiene is also a key preventative factor when dealing with pathogens that are typically transmitted through the fecal-oral route. Hygiene specifically refers to practices that can lead to better health and cleanliness, such as frequent washing of the hands and face, along with bathing with soap and clean water[15]. Practicing personal hygiene in many parts of the world can be difficult due to lack of access to sufficient water and soap. Maintaining clean hands can significantly reduce the spread of fecal pathogens[16], along with preventing person to person transmission. This can also have an impact on drinking water quality particularly in areas where drinking water is not often poured out of the storage container but rather dipped out by some means. When soiled hands come into contact with the otherwise good water, they have a good probability of polluting it[17]. For example, researchers in Honduras examined potential pathogenic pathways for fecal contaminants in households[18]. They found several different mechanisms that contributed to the deterioration of water quality but argued that hands have the greatest potential to introduce contaminants because of the many occasions where contact with drinking water can and does occur[18].

Employing proper methods of sanitation also plays a significant role in the health and livelihood of everyone around the world. Even though gains are being made toward better sanitation and access to clean water, in 2006 there were still 54 countries that had information indicating that less than half the population used an improved sanitation facility[8]. An improved sanitation facility is defined as one that hygienically separates human excreta from human contact[9]. Descriptions of what types of facilities are considered improved or unimproved are listed in Table 2.

Table 2: Examples of improved and unimproved sanitation facilities[9]

Sanitation facilities	
Improved	**Unimproved**
Use of following facilities in home/ compound:	Use of following facilities anywhere:
> Flush/pour-flush to:	- Flush/pour flush to elsewhere
- piped sewer system	- Pit latrine without slab/open pit
- septic tank	- Bucket
- pit latrine	- Hanging toilet/hanging latrine
> Ventilated improved pit (VIP) latrine	> Use of a public facility or sharing any improved facility
> Pit latrine with slab	> No facilities, bush or field (open defecation)
> Composting toilet	

Improved sanitation facilities like latrines and flushing toilets allow people to dispose of their waste appropriately, which can help to break the infection cycle of many diseases[15]. For those lacking improved sanitation, over 1.2 billion still have to perform open defecation[8]. Without proper sanitation, it becomes very difficult to practice good hygiene and maintain safe water quality. For example, if no latrines are available in a community, there is a high likelihood that the local water sources will become contaminated with fecal material after open defecation occurs[3]. Even if residents are not openly defecating, they may be using a bucket or pot of some sort that they will eventually have to empty manually. This could also provide a mechanism by which fecal contaminants reach the water source. Along the same lines, there will be an increase the potential of fecal-oral transmission if the hands of the one who empties the container are not cleaned properly afterwards[16]. Well over two billion people are currently without improved sanitation[8], and are at risk for numerous infections and diseases related to this insufficiency. Safe sanitation is a key solution to aid in the breakdown of transmission routes for fecal-oral pathogens that often infiltrate water systems[3].

Providing access to safe water and sanitation facilities, and promoting proper hygiene behavior are important barriers in reducing the burden of disease from not only diarrhea but also other sanitation and hygiene-related diseases. Figure 1 is an F-diagram describing transmission pathways for fecal-oral contaminants leading to disease[19]. As indicated in the diagram, there are various opportunities during the path of transmission to stop the disease cycle by implementing access to clean water, hygiene and sanitation.

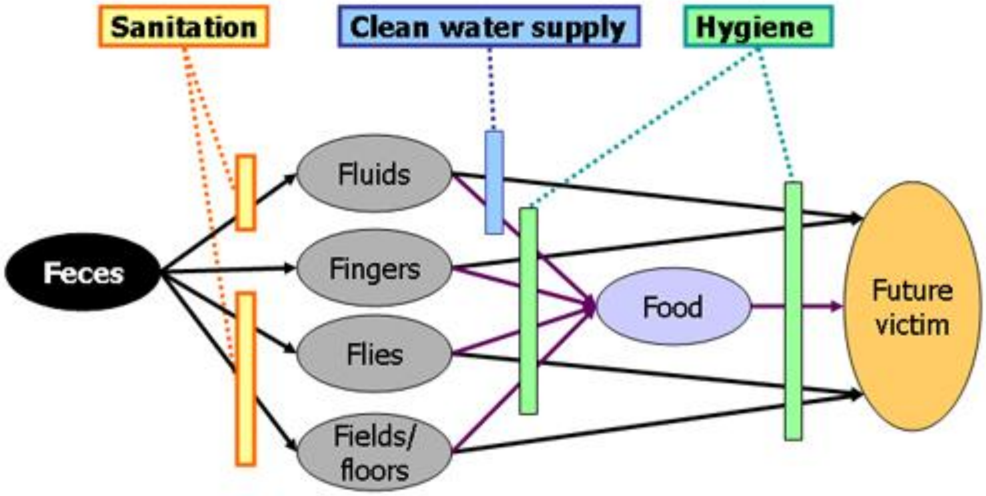

Figure 1: Routes of fecal-oral disease transmission and protective barriers

For example, malnutrition is another affliction that water, sanitation and hygiene have a considerable impact on[3]. The Millennium Development Goals estimate that the average per capita rate of healthy life years lost to childhood malnutrition are twelve-fold higher in developing nations than in those that are already developed. There is also is 60-fold difference between the rates for the WHO sub-regions with the highest and lowest malnutrition rates[13]. An estimated 50% of cases of children who are either underweight or malnourished are associated with repeated diarrheal or intestinal nematode infections. These are both a result of insufficient hygiene or inadequate sanitation and result directly in about 70,000 child deaths per year. Undernourished children also become more susceptible to infectious disease, so this indirectly leads to the death of an additional 860,000 children[7].

Water vectorborne diseases such as malaria also play a major role in the transmission of disease and deaths worldwide with nearly a million deaths due to malaria each year[13]. A significant proportion of other various diseases, including: trachoma, schistosomiasis, ascariasis, trichuriasis, and hookworm[3], could be prevented through better access to adequate sanitation facilities and better hygiene practices, and more importantly with better quality water[15].

Access in the Dominican Republic

According to the Joint Monitoring Programme, currently 95% of the households in the Dominican Republic have improved water sources and 78% have some form of improved sanitation[20]. In rural areas, these improved water and sanitation rates drop down to 91% and 74%, respectively[8]. The most common form of improved sanitation in rural Dominican Republic is a private covered dry latrine, and this is used by almost half (47.3%) of residents in these areas. On the other hand, the majority (27.9 %) of people living in more urban areas tend to use private flush toilets that are connected to a septic tank[8]. Over 10% of inhabitants residing in rural areas and 2% living in urban regions still lack improved sanitation facilities and resort to open defecation[21]. Reducing the number of those with unimproved or improving existing sanitation facilities could significantly increase the health and well-being of the nation.

As stated earlier, access to improved water sources in the Dominican Republic is more prevalent than access to improved sanitation facilities. As of 2003, the most widespread source of drinking water in both urban and rural areas was piped water supply to the house or yard connections (86% and 54%, respectively)[22]. Although, in rural locales, the second most common water supply used is either a pond or stream.

Overall, the proportions of people in all regions of the Dominican Republic with access to improved water have increased significantly over the past decade[22]. Access to improved water may seem significantly high (95%) for a developing country. However, bottled water is considered an improved source of drinking water in the Dominican Republic by measures of the JMP[9]. This is because bottled water is mainly used as a better alternative than tap water[22]. Unfortunately, bottled water may not be as sustainable as other improved sources. Many times people will have to make decisions about purchasing bottled water in times of limited financial resources. Even though bottled water is most likely safer than well, river or borehole water, often times the bottled water is transferred to some other vessel before being served[23]. By doing so, the people handling the water and containers have more opportunities to contaminate an otherwise safe drinking source. Trevett *et al.* found that substantial water quality deterioration occurs between the collection site and ingestion[17]. Conclusions drawn from this study indicated that the individual household participants were responsible for the pollution, and it was not a result of environmental conditions, because all experienced them same circumstances. It was also determined that household water quality did not improve over the period of the study, which suggested that there was no significant observer effect that led to any changes in household water collection and storage practices. Water deterioration continued to be a widespread problem in the study community and was observed at least once in 95% of the households[17].

2.2 Burden of diarrheal disease in underdeveloped areas

Consuming water free of pathogens is fundamental to halting one of the primary modes of transmission of infectious diseases but around the world limited access to improved water and sanitation make this vital step extremely difficult. The effects of not having adequate sanitation and drinking water can be seen by looking at the disease burden caused by those factors. According to Bern *et al.* diarrheal diseases, due to bacterial, viral and parasitic pathogens of gastroenteritis are the most important groups of water related infections. They are also deemed a leading cause of childhood morbidity and mortality worldwide[2].

Worldwide disease burden

The quality of drinking water directly affects the welfare of individuals with cumulative effects at all societal levels around the world. Four percent of all deaths and 5.7% of the global disease burden has been attributed to water related illnesses[24]. Infectious diarrhea is the largest contributor to the disease burden due to water, sanitation and hygiene. Around the world there are great variances in the disease burden of diarrhea, and this can be seen by looking at the world's lowest rate (0.2) of disability adjusted life years (DALYs) per 1000 people for environmentally caused diarrhea observed in several different countries[2], compared to the highest country rate in Niger of 107[20]. The highest estimated death rate (350.4/100,000 people) and DALYs (11,377/100,000 people) attributable to diarrhea in general were both observed in Niger. The lowest rate of zero deaths at all for 2004 was seen in Hungary, Latvia, Poland, and Serbia and Montenegro, and San Marino had the lowest number of DALYs (22/100,000 people)[25]. The United States, even though a highly developed country, was still not in the lowest rankings for either DALYs or death rates, with 33 and 1.5/100,000 people, respectively.

Typically disease burden estimate regarding diarrheal diseases are based on acute infections, and do not take into account the long term effects that may occur due to repeat or prolonged exposures[26]. Long term deleterious effects on growth and development have been implicated to be a result of asymptomatic enteric infections[26]. Enteric infections have also been associated with lasting physical and cognitive impairment in children[5].

As with many diseases, children are more susceptible to enteric infections due to the absence of acquired immunity, lack of adequate healthcare facilities and quite possibly lack of education about sanitation, hygiene, and the spread of disease. Untreated water supplies are readily polluted by fecal matter, resulting in elevated background levels of infectious diarrhea in developing countries (5-12 episodes per child/year)[27]. In developed countries, this level is much lower and the prevalence of diarrhea is about 2 episodes per child/year[27]. Previous work has determined that children under three years of age averaged 5.25 diarrheal infections each year, and about 8% of these illnesses were persistent in developing countries[28]. Every year about 1.5

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[2] Andorra, Australia, Austria, Belgium, Croatia, Czech Republic, Estonia, Finland, Germany, Greece, Hungary, Iceland, Italy, Japan, Latvia, Malta, Netherlands, New Zealand, Poland, Portugal, San Marino, Spain, Sweden, and Switzerland

million children's' deaths are attributable to diarrhea[29], and over 80% of those deaths were children under the age of two[30]. In developing countries, along with losing their lives, children lose eight times more healthy life years than do their counterparts in more developed regions[3]. Nutritional shortfalls and malnutrition are major problems associated with recurrent diarrhea. This malnutrition can lead to a vicious cycle of unhealthy life, predisposing children to diarrheal illnesses and vice versa[28].

Disease burden in the Dominican Republic

The Dominican Republic is a rapidly developing county, but there are still major deficits in various social aspects of the growing area. For example, more than 40% of the nation's inhabitants still live below the national poverty line[31]. Although, only 3% of the population lives below the international poverty line of less than one dollar a day[32]. The country's rapid population growth, increased migration to urban areas, and escalating numbers of people living in poverty have resulted in serious insufficiencies in the access to and quality of water and sanitation services. This is part of the reason why epidemics of acute diarrheal disease occur frequently in tropical developing countries like the Dominican Republic[33].

Due in part to quickly becoming more developed, the Dominican Republic has an overall lower diarrheal disease burden than the average for the world as a whole. Among children, the proportion of deaths due to diarrhea among children under five is 11.8%, the global mortality for those less than five is 16.8%[8]. Within the Dominican's population of 9.8 million people there it is estimated that approximately 1,300 deaths each year that are linked to diarrhea caused by water, sanitation and hygiene risk factors[20]. Not only does water, sanitation and hygiene related diarrhea lead to death, but it also generates approximately 5 DALYs per 1000 capita each year[20].

When compared to the highest and lowest country rates reported earlier, this rate is much closer to the low end of the spectrum in terms of environmentally related illness and disease. Haiti, even though sharing an island with the Dominican Republic, has a much higher yearly rate of 23 DALYs per 1000 capita[20]. In the Dominican Republic diarrheal diseases in general generate 538 DALYs per 100,000, and as of February 2009, there is a death rate of 15.6 per 100,000 people due to diarrhea[25]. Compared to other nations, this level is once again quite low.

2.3 Factors affecting drinking water contamination

Additionally, it is necessary to look -at the physical, behavioral and environmental factors related to drinking water contamination during collection and storage.

Environmental

The environment plays an integral role in the transmission of hundreds of diseases worldwide. The WHO has determined that the environment significantly affects more than 80% of these major diseases, one way or another[34]. Environmental factors can either directly or indirectly affect a pathogens survival, persistence and ability to produce disease. A recent report has estimated that environmental risk factors contribute to almost a quarter (24%) of the global disease burden from all causes in DALYs, and also to 23% of all deaths[35]. The developing world is disproportionately affected by environmental risk factors and nearly one third of deaths in these regions are due to environmental causes[34]. This is largely due to variations in exposures to risks and access to health care. In the WHO determined “most-impacted” sub-regions, the environmental burden of diarrheal diseases and lower respiratory infections was 150 and 120 times higher, respectively, when compared to those least impacted[3].

Children are another group also impacted substantially more by environmental-related diseases than others. This is especially true for children younger than five years old. An estimated 33% of disease in children under five is caused by environmental exposures[35]. Worldwide, the number of healthy life years lost to environmental risks was close to five times greater in children under five years than in the rest of the population. This difference is even more substantial (about 7-10 times greater) for major diseases such as diarrhea, malaria, malnutrition, and upper and lower respiratory infections[3]. When looking at specific diseases, these per capita rates increase dramatically. For example, in developing areas, sub-regionally children experience losses of 140 times more healthy life years for diarrheal disease and 800 times more for lower respiratory infections than developed regions[3].

Much of environmental-related disease is easily preventable, and the transmission could be altered dramatically through policy changes or the utilization of technologies that already exist[35]. Significant portions of the world's two largest childhood killers, malaria and diarrhea, could be prevented through better environmental management (over 40% and 94% respectively)[34]. Millions of unnecessary deaths attributed in some way to the environment could be adverted every year through simple changes, and this includes about 1.5 millions child deaths due to diarrhea alone[7]. These changes include anything from the use of cleaner and safer fuels, to the promotion of safe household water storage and better hygienic practices, built environments with increased levels of safety, and more cautious use and management of toxic substances around the home and workplace[35]. These along with several other modifications can lead to a safer and much healthy world. As many as four million children per year could have their lives spared by preventing certain environmental risks[34].

The World Health Report given in 2004 indicated that of 85 of the 102 major reported diseases are at least partly caused by exposures to various environmental risk factors[36]. Of these, the four major diseases most influenced by weak environments are lower respiratory infections, malaria, various forms of unintentional injuries and diarrhea[34]. These types of diseases have extremely strong correlations with a range of environmental factors such as temperature, rainfall, particulate matter, and humidity[37]. There are several diseases prevalent in tropical climates that are linked to waterborne transmission. Diseases such as malaria and eastern encephalitis are transmitted via the mosquito, the life cycle of which is dependent on temperature and precipitation[37]. An increase in water in an area, particularly from flooding, may directly impact the number of mosquitoes and other water-breeding insects, potentially generating high-risk environments for disease[15]. It has been estimated that over 40% of the global malaria burden, about half a million people, could be prevented annually by successful environmental management[3]. If the transmission between hosts does not involve vectors, then water, or at least humid conditions, can be implicated in transmission[38]. Diarrheal disease is a good example of this scenario, and it has the highest environmental contribution by far[35]. An abundance of rain can easily lead to the contamination of ground water with fecal matter, and in turn diarrheal disease[33]. Most waterborne diseases cause diarrheal illness, and these cases result in 1.5 million deaths each year, mostly in young children[7].

It has been determined that by modifying environmental risk factors for disease and injury there could be a significant reduction of the disease burden a region faces[3]. The potential health gains from these interventions could be astronomical. For example, in 2002, 1.1 billion people, mostly in developing countries, were still using potentially harmful sources of water. At the same time, over 2.5 billion people lacked something as basic as a simple improved latrine[6].

Physical

Various physical aspects can have a significant impact on and affect the quality of drinking water. In the case of infectious diarrhea, transmission routes are affected by interactions between the physical infrastructure and human behaviors[3]. When latrines and hand washing facilities are inadequate and feces are a disposed of improperly, fecal material may contaminate a person's hands and from there be transferred onto food (fecal-oral route) or another person (person-person transmission). Even when adequate latrines or toilets are present, fecal pathogens can be easily flushed through the water sewage system, and this may subsequently contaminate surface and ground waters[3].

Along the same lines, inadequacies in the engineering of water systems will significantly increase the possibility of contamination at some point during the route to consumption. Although the facilities may be developed, the routine maintenance or monitoring may not be carried out due to an assortment of issues[33]. The drying up of wells and constantly breaking pumps are two of the main causes of water system failures. Hunter *et al.* have shown that even minimal days of interrupted supply of clean drinking water may be sufficient enough to destroy the health benefits provided by uncontaminated drinking water[11]. Without a continuous water supply, a situation may arise that could possibly promote the growth of bacteria within piped water systems, tanks and wells during periods of nonuse[33]. Other physical problems may be caused by situations such as fuel shortages and incompetent personnel who fail to actually turn on the pump[10]. Fuel shortages can actually have an adverse effect on the in-home treatment processes as well. Without enough fuel, households may try to conserve as much as possible, and they may not boil their water at the correct temperature or long enough[33]. In some places well built and continuously working systems are still not sufficient due to poor planning. For example, the water dispersion pipes may either travel through or be submerged under sewage. If the water flow is intermittent in the types of piped systems where water and sewage lines lie directly next to one another, the chance of contamination is even greater due to the negative pressure created by the lack of water[39].

Some of the most optimal approaches to preventing waterborne diseases or illnesses are through physical measures. Protecting water sources from pollution or contamination, for instance, will provide a great deal of security to potable water. In addition, construction of sewage treatment facilities and water disinfection and delivery systems are great preventative measures[33]. Even if these improvements are made in developing regions, it will be imperative to maintain the functionality of these water sources in order to provide the best possible water quality to the inhabitants of that area.

Behavioral

Compared to both environmental and physical factors, human behavior may be the hardest to change. It is important to evaluate both attitudes and practices among the intended population before trying to implement intervention strategies targeted at provision of better quality drinking water and deterrence of disease[33]. Certain behaviors are often taught and instilled beginning at very young ages, and are typically can be hard to alter later in life. By providing clean water and latrines at primary schools in developing areas, children will be encouraged to come to school[13]. This will aid in enhancing not only the children's' academic knowledge, but also their knowledge about good hygiene habits.

Hand washing is habitual behavior that is taught, and may take place in one home and not it the one next door. The practice of hand washing was studied in rural Honduran communities in 2000. Women in these communities were asked to go about their daily rituals and were observed within the home by a researcher. The women were then asked to place their fingertip into a container of sterilized distilled water and the water was analyzed for fecal contaminants. Nearly half (44%) of the women's fingertips tested positive for fecal material contamination[18]. Each of the finger-to-water contact times were only about two to three seconds long, indicating how quickly and easily it is to transfer fecal coliforms. An associated study showed that household water quality varied greatly day by day, and this led the researchers to conclude that the individuals in the household were actually responsible for the contamination[17].

Several research projects focusing on improving water quality also have a hygienic behaviors component in order to assess what is actually going on within the household in regards to hand washing and other measures of cleanliness. One analysis of a hygiene behavior questionnaire suggested an association between low hygiene scores and an increase in contamination of stored water[33].

2.4 Household drinking water storage and treatment practices

In addition to examining access to improved water, sanitation and therefore increase hygiene practices, it is also important to examine existing household drinking water storage and treatment practices in regions where these are lacking. This may also provide insight into intervention mechanisms to reduce fecal contamination of drinking water. Often, household storage of water has been associated with evidence of increased fecal contamination, with levels of contamination depending on a number of factors including the site of storage, type of container and handling practices[33].

Practices in the developing world

In developing countries, even if drinking water is collected from a safe source, it can become contaminated before being consumed by members of the household. This contamination can occur during the collection and storage of water within the household[17]. Through various studies, stored water has actually been found to contain more contamination than tap or piped water[33, 40-41]. There is an increasing need to understand the impact of household drinking water collection, storage and management practices to understand impacts on water quality and prevent ineffective interventions and wasting of resources.

In numerous parts of the world access to water is scarce and intermittent, and when it is actually available, consumers will attempt to collect and store as much as possible to last until the next supply becomes available. In these situations, water needs to be stored for not only drinking, but also food preparation, washing and bathing[33]. Even if a household is connected to a municipal water supply, they may still need to store water if the supply is only available during certain intervals through the day. Therefore, household or domestic water storage is a necessity for both those who depend on a drinking water source either outside of the home and also those connected to an interrupted source within the home. Another major reason for the household storage of water in developing countries is the distance from the source. The further the water source is from the home, the more water a household would like to store at a time[42]. This practice of storing water in the home can typically last anywhere from hours to days depending on the current availability. This length of time is adequate for the introduction of fecal contamination into basically good quality drinking water[43]. One hypothetical source of contamination may be the presence of children in the home where water is being stored. Children can introduce contamination through the use of fecally contaminated hands or utensils with the household storage container. This pathogenic pathway is independent of contamination at the water collection site[44].

Various studies have been performed to evaluate and understand on the mechanisms of drinking water contamination occurring at the public water sources, but few have looked at the relationship actual storage practices have with the quality of drinking water within the household[43]. After the work by Feachem *et al.*[45], very few studies have concentrated on the difference between drinking water contaminated at the source and water contaminated in the home. In turn, those that have looked at the public and domestic levels as two separate points of possible contamination found their studies to be inconclusive[43]. One study done in 1993 suggested that contamination that occurs within the house basically poses no harm to those making up the household[46]. This was based on the premise that any contamination that occurred after being stored in the home was a simple recycling of already present microorganisms found within the household to which the members have already formed some level of immunity[46]. This same study also suggests that even if there is no such immunity, it is more likely that other household transmission routes, like food contamination and person to person contact, played a much larger role in the pathogenesis of fecal contaminants[46].

While drinking water contamination during storage in the home is important to understand and examine, it is also important to understand various household practices and beliefs surrounding household water management. There are various water storage practices and beliefs around the world, and it is important to look into some of these to determine if certain developing communities are utilizing methods that are more efficient at removing or preventing contamination than others. One of the most obvious factors that may affect drinking water quality is the selection of the drinking water. In developing areas water can be collected from a wide variety of sources, including: wells, boreholes, piped systems, rivers or streams, and rain. It has been estimated that 1.5 billion people depend on engineered water systems that require collection, transport and storage in the home but the remaining portion of rely on either using water directly from a tap[47].

The composition of storage containers used to store drinking water is important as well and can vary anywhere from extremely large plastic or metal containers to small single serving glasses. In many areas clay pots or pitchers are used, and in other plastic or metal containers may be more abundant[5, 33, 48]. Many studies have contradicting findings about the effect on the quality of water by the type of vessel it is stored in. One group of researchers found that the material from which the container was composed of had no significant advantage or disadvantage n terms of the stored water quality[17]. Another study indicated that the type of material did make a significant difference in the quality of water. Water tested in this study that had been stored in brass pots was less contaminated than pots made of other materials. Additionally, it was determined that earthenware pots showed a much slower decline in *E. coli* counts than all others. This was determined through work done both in the field and in the laboratory[33].

Other important aspects of household water storage include various methods of retrieving drinking water for consumption from the storage container. In some households where a spigot or spout is not present, various instruments are used to retrieve water from the storage container. These utensils can be anything from a cup or ladle to a pitcher. Some households choose to scoop the water out with their bare hands. In other instances no alternate dipping device is used, instead the drinking water is be poured directly from the opening at the top of the vessel. Water sources can easily become contaminated by unhygienic water drawing practices[33].

Some types of containers appear to be much better at preventing contamination once the water has been collected and brought into the home. For example, a study done in Punjab, Pakistan looked at the types of containers being used and their associations with *E. coli* levels. Traditional wide-necked pitchers were compared to modified narrow-necked pitchers to determine *E. coli* numbers in household drinking water. The only difference between the two pitchers was a five inch difference in the diameter of the neck. It was found that the smaller opening prevented people from dipping their hands or other possibly contaminated items into the water, and in turn, reduced the risk of contamination within the home[43]. Other studies have found similar results when implementing small-necked vessels that prevented people, especially children, from putting their hands directly into the water[48-49].

However, in some areas it may not be practical to use narrow-necked containers for water collection. This was seen in a study in south India, where it was observed that the low pressure at which the water was being retrieved made it necessary for the use of a hand or motorized pump to ensure the quick filling of collection vessels. As a result, the stream of water became larger than the opening of the container, thereby causing spillage and a waste of water[33]. Narrow-mouthed containers may also prove difficult to use if they are too large. Since the opening is so small, no dipper can enter the mouth, so the water must be poured. The larger the vessel, the more difficult this task becomes.

Other important aspects for water storage that may be associated with fecal contamination include covered containers. Some households place some sort of covering over their storage containers, while others do not. Covering a storage container may have little to no protective effect for the water, especially if the lid is continuously being taken on and off. A study in Honduras found that there was no significant difference in the quality of water stored in either covered or uncovered vessels[17]. The size and volume of storage containers can vary just as frequently as the types of material they are made of. One study in Honduras looking at about thirty households observed storage containers with volumes ranging anywhere from 15 to 201 capacity[18]. Even though container volumes can vary greatly, researchers determined that the degree of contamination may not be significantly affected by the amount of water remaining in the container during sampling[33]. On the other hand, it has been determined that one of the key factors influencing the impact of storage vessels and conditions on household water quality is the size of the container the water is stored in[50].

Finally, often times households will employ some sort of treatment method prior to consumption. This, along with the type of container used during the storage of drinking water, is important in determining the microbiological quality of the water too. In underdeveloped regions boiling may be one of the simplest ways to achieve a better quality of drinking water, and if done properly, should eliminate all fecal coliforms. A study by VanDerslice and Briscoe actually concluded that boiling water had a more significant impact on its levels of contamination than does the type of container it is stored in[46]. Often times, though, water is boiled for too short of a duration or either at too low of a temperature, and is not as effective at completely eliminating any contaminants[33]. Another technique of water treatment in developing and developed countries alike is the process of chlorinating the water. This can be done with the use chlorine in the form of liquid, tablets or powders. One study found that fecal contamination was still present in households using a specially designed safe water storage container, but not in households using both the container and a 5% calcium hypochlorite solution[48]. In some instances, chlorine additives are not accepted by all because of the effect they have on the color, taste and smell of the water[33]. Field research has determined that often times the amount of chlorine being added to the water is not sufficient to achieve WHO standards[39]. Acceptable residual chlorine levels should be between 0.2 and 0.5mg/L in order to for the chlorine to retain its disinfectant capabilities[51].

Filtration is also a relatively easy procedure that can be done to remove a great deal (but not all) of the contaminants from drinking water. Several different methods of filtering are used worldwide, and some of these may employ apparatuses like ceramic candle filters, cloth sieves, and biosand filters. Previous research has found that when participants of studies report having either boiled or filtered their water, microbiological testing indicated that contaminants were still present[33]. Filters are not typically completely effective at removing all contaminants due to inadequate pore sizes which trap larger pathogens, but may allow the smaller ones to slip through.

Solar disinfection (SODIS) is by far the cheapest method of decontaminating water, and also one of the safest[52]. Solar radiation can remove a wide variety of organic chemicals and pathogenic organisms from water with the use of ultraviolet rays from the sun and clear plastic bottles[53]. The main disadvantage of SODIS is that bacterial inactivation rate is proportional to sunlight intensity and atmospheric temperature, while at the same time inversely proportional to the depth of the water[52]. This means, if a deep container is being radiated on a cool or cloudy day, the rate of disinfection is going to be dramatically slower than it would be on a sunny warm day.

Sedimentation and aeration are also physical methods for treating drinking water, and they have high levels of availability and practicality. Even though both methods are inexpensive and not technically difficult, they are less beneficial than other decontamination techniques because they provide low microbial removal efficacies[50].

Practices in the Dominican Republic

Storage practices in the Dominican Republic are very similar to those in other developing countries. People in the community obtain their water from various sources, use a wide variety of storage containers and may or may not use a variety of common methods of treatment for their drinking water. Like in other developing nations, the people of the Dominican Republic use several different types of storage containers for their household water depending on their personal preferences and also on what is available. A 2004 case study found that fifty-five gallon drums are the most frequently used type of storage container, and are found in practically every home[54]. Often, boiling is the most common method for purifying household drinking water used in the Dominican Republic, especially if the water is going to be given to an infant[55]. Chlorination and filtration were other methods that are used for drinking water disinfection in the Dominican[56]. Availability of bottled water in a household is also seen as an approach to provide members of the household with improved drinking water[55].

CHAPTER III: METHODOLOGY

3.1 Data Sources

All data used in this study was de-identified secondary data and available via Dr. Christine Stauber. The data is a compilation of data from a cross-sectional study done in the summer of 2005 and data from a longitudinal study done between August 2005 and January 2006. IRB approval was granted through the Georgia State University Institutional Review Board Protocol H10061.

3.2 Research Setting and Study Population

A cross-sectional survey was given to randomly selected families in Bonao in June 2005. These families were located in six different communities named: Jayaco Arriba, KM 103, KM 101, KM 100, Majaguay, and Brisas del Yuna. Cross-sectional surveys included information on education, sanitation and hygiene practices, containers for water storage, water usage purposes (such as bathing, drinking, cooking, etc.), and the methods used to serve water. Questions about the make-up of the households (# of adults & children), along with other information about the family and home were incorporated to provide a basic understanding of the study participants. In order to gain insight into why certain practices were chosen over others, beliefs about hygiene, sanitation, and diarrheal disease were also included in this survey. This information formed a baseline understanding regarding typical procedures involved in household water collection and management, and how widely these varied among households. The basic requirement for inclusion in the studies was a household's willingness to participate and the presence of at least one child under the age of five residing in the home. All households with children under the age of five were targeted for recruitment because the diarrheal disease burden falls heavily and disproportionately on this age group.

After completing a cross-sectional survey in June-August 2005, all households were then enrolled in a prospective cohort. The prospective cohort required weekly surveys and drinking water sample analysis at approximately two week intervals. Households were visited approximately eight times over a four month period from September 2005 to January 2006. Initially, approximately 186 households began participating in the prospective cohort. However, those numbers decreased over the length of the study. Families were interviewed weekly and had water samples collected from their storage containers every two weeks. During water sample collection, data were collected on water source, type of storage container and any drinking water treatment performed at the household at each visit.

Household interviewers listed the type of container for drinking water storage. In order to examine the impact of size of the container opening, each type of storage container was classified as either wide- or narrow-mouthed based on the diameter of the container opening and they were also classified as large or small volume based on the approximate volume of water that could be stored in the container. In addition, relevant observations on hygiene behavior and water usage were also made during the visits (e.g. hand washing, presence of soap, etc.).

3.3 Data Analysis

Descriptive statistics

Descriptive statistics about each participating household based on their community location and family composition (number, ages, sex) were generated to describe various demographics of the cohort. There were 22 households that did not complete the cross-sectional interview and therefore data were not available regarding these various statistics and have been classified as missing.

Drinking water quality testing

In addition to a cross-sectional survey and weekly household surveys (which were not specifically analyzed here), participants provided samples of drinking water every two to three weeks to interview staff. As previously described, drinking water was collected from each storage vessel and placed into a sterile container before being analyzed for *E. coli* concentration, total coliforms, turbidity, and chlorine levels[57]. Drinking water was sampled nine times during the course of the study although most households did not provide drinking water samples over all nine sampling periods.

The parameters selected for measurement of water quality included total coliforms, *E.* coli as an indicator of fecal contamination, and turbidity. Total coliforms and *E. coli* levels were determined by the most probable number (MPN/100mL) method using IDEXX Colilert Quantitray 2000, and the water quality results in this paper are reported in terms of MPN/100mL. Since the microbiological data exhibited an extremely skewed distribution, MPN values for total coliforms and *E. coli* were $\log_{10}$ transformed to obtain an approximately normal distribution. Further analysis also classified *E. coli* counts into risk groups by the system proposed by Lloyd and Helmer (1991). Categorizations were made according to the magnitude of contamination and included the following groups: <1 MPN/100mL, 1-10 MPN/100mL, 11-100 MPN/100mL, and >100 MPN/100mL.

3.4 Analysis

Data from interviews and household visits and water quality analysis were merged in Excel and then exported to Stata 10th Ed (College Station, TX). Stata 10 was used for all statistical analyses. Two sample t-tests were used to compare mean differences in level of contamination by source and type of storage. Linear regression was used to examine individual associations between concentration of *E. coli* and risk factors for contamination including: original source of water, storage practices and beliefs.

CHAPTER IV: RESULTS

4.1 Demographics

At the start of the longitudinal study (September 2005), 186 households were enrolled. During the longitudinal study (between September 2005 and January 2006), another twenty households left the study. The primary reasons for doing so was either the participants moved or the child under the age of five left the household.

Household demographics are shown in Tables 3 and 4. The majority of households were from the community Brisas del Yuna (60 households). Twenty-nine households from Jayaco Arriba participated in the study, while another 22 households were from Majaguay. The communities KM 100, KM 101, and KM 103 had 17, 24, and 33 households included in the study, respectively. Households had anywhere from three to eleven members, but most commonly there were five individuals per household.

Table 3: Participating household characteristics reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

		Number of people living in household								
Village	**Households N(%)**	**3 N(%)**	**4 N(%)**	**5 N(%)**	**6 N(%)**	**7 N(%)**	**8 N(%)**	**9 N(%)**	**10 N(%)**	**11 N(%)**
Brisas del Yuna	60(32)	3(6.1)	12(24)	15(31)	7(14)	6(12)	3(6.1)	2(4.1)	1(2.0)	0
Jayaco Arriba	29(16)	5(16)	8(26)	8(26)	6(19)	2(6.5)	0	1(3.2)	0	1(3.2)
KM 100	17(9.5)	2(14)	3(21)	4(29)	3(21)	1(7.1)	1(7.1)	0	0	0
KM 101	24(13)	2(10)	2(10)	6(29)	8(38)	1(4.8)	1(4.8)	1(4.8)	0	0
KM 103	33(18)	8(26)	5(16)	7(23)	5(16)	1(3.2)	2(6.5)	3(9.7)	0	0
Majaguay	22(12)	0	2(12)	4(24)	1(5.9)	4(24)	3(18)	2(12)	1(5.9)	0
Total	**185**	**20(12)**	**32(20)**	**44(27)**	**30(18)**	**15(9.2)**	**10(6.1)**	**9(5.5)**	**2(1.2)**	**1(0.61)**

A requirement to be included in the studies was to have at least one child under the age of five years old living there, but analysis of the data indicated that initially seven households had reported no children younger than five. More than 100 households had a single child below the age of five living in the home; forty households had two kids under five, and another eleven had three children below five years old (as shown in Table 4). Typically the respondent for each household was the woman of the house.

Table 4: Number of children under five living in household, by community reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Number of children under 5 living in household			
Village	**0 N(%)**	**1 N(%)**	**2 N(%)**	**3 N(%)**
Brisas del Yuna	0	29(59)	14(29)	6(12)
Jayaco Arriba	2(6.5)	25(81)	3(9.7)	1(3.2)
KM 100	1(7.1)	9(64)	3(21)	1(7.1)
KM 101	1(4.80	11(52)	8(38)	1(4.8)
KM 103	2(6.5)	21(68)	8(26)	0
Majaguay	1(5.9)	7(41)	7(41)	2(12)
Total	**7(4.3)**	**102(63)**	**43(26)**	**11(6.8)**

4.2 Indicators of hygiene

As part of the initial cross-sectional interview, participants were questioned about their day-to-day hygiene practices. Focus was placed specifically on issues related to handling of the household drinking water. Presented in Table 5 is a description of the responses regarding drinking water collection container cleaning practices for each community. All but four respondents indicated that they washed the container used to gather water. When asked what was used to clean the container, the majority answered soap and water or some other cleaning compound (98 and 88 people respectively). Seventy-six percent of both Majaguay and KM 101 household respondents reported using soap and water when cleaning the containers used for collecting drinking water. Bleach was the solution another 35% of respondents indicated utilizing for washing the vessels, and Jayaco Arriba and Brisas del Yuna had the greatest proportion (48% and 51%, respectively) of respondents who used a bleach cleaning solution for washing. Almost half (49%) of the household respondents reported that they cleaned the drinking water collection container every time water was collected. Two communities, KM 101 and KM 103 were the communities that had the largest proportions of participating households reporting this practice. Four household respondents from all communities combined reported washing their container only once a month, while 27 said they cleaned the container once a week. Another 30% of primary household respondents declared some other frequency at which they cleaned their vessel.

Table 5: Household cleaning practices applied to drinking water collection containers reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Washed container		**Container cleaned with***			**Frequency container cleaned**			
Village	Yes N(%)	No N(%)	Soap & water N(%)	Bleach N(%)	Other N(%)	Every refill N(%)	Once a week N(%)	Once a month N(%)	Other N(%)
Brisas del Yuna	49(100)	0	29(59)	25(51)	20(41)	19(39)	8(16)	2(4.1)	21(43)
Jayaco Arriba	30(97)	1(3)	18(58)	15(48)	14(47)	18(58)	3(9.7)	1(3.2)	8(26)
KM 100	14(100)	0	10(71)	4(29)	10(71)	4(29)	7(50)	0	3(21)
KM 101	19(90)	2(10)	16(76)	2(9.5)	13(68)	13(62)	3(14)	0	4(19)
KM 103	30(97)	1(3)	12(39)	4(13)	22(73)	19(61)	2(6.5)	1(3.2)	9(29)
Majaguay	17(100)	0	13(76)	7(41)	9(53)	7(41)	4(24)	0	6(35)
Total	**159(98)**	**4(2)**	**98(60)**	**57(35)**	**88(55)**	**80(49)**	**27(17)**	**4(3)**	**51(31)**

* Responses are not mutually exclusive

The same set of questions were asked about the container the household drinking water was actually stored in, and once again all but four people reported washing their drinking water storage containers (Table 6). The results were similar to those for collection containers. The washing frequencies were about the same as well, and again most household respondents reported washing the container every time it was refilled. The largest difference between the cleaning of collection and storage containers was that fewer (7% less) respondents used a cleaning method other than soap and water or bleach to wash their storage containers.

Table 6: Household cleaning practices applied to drinking water storage containers reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Washed container		**Container cleaned with***				**Frequency container cleaned**				
Village	Yes N(%)	No N(%)	Just water N(%)	Soap & water N(%)	Bleach N(%)	Other N(%)	Every refill N(%)	Once a week N(%)	Once a month N(%)	Other N(%)	Doesn't know/ no response N(%)
Brisas del Yuna	47(96)	2(4.1)	0	28(57)	25(51)	17(10)	18(37)	12(24)	1(2.0)	16(33)	0
Jayaco Arriba	31(97)	1(3.2)	0	21(68)	13(42)	13(8.0)	19(61)	2(6.5)	1(3.2)	8(26)	0
KM 100	14(100)	0	0	10(71)	4(29)	8(4.9)	5(36)	4(29)	0	5(36)	0
KM 101	21(100)	0	0	16(76)	3(14)	13(8.0)	15(71)	2(9.5)	0	3(14)	0
KM 103	30(97)	1(3.2)	1(3.2)	10(32)	2(6.5)	22(13)	19(61)	2(6.5)	0	6(19)	1(3.2)
Majaguay	17(100)	0	0	13(76)	8(47)	6(3.7)	5(29)	4(24)	1(5.9)	7(41)	0
Total	**159(98)**	**4(2)**	**1(0.61)**	**98(60)**	**55(34)**	**79(48)**	**81(50)**	**26(16)**	**3(1.8)**	**45(28)**	**1(0.61)**

* Responses are not mutually exclusive

An additional part of the questionnaire evaluated basic beliefs about water safety and hygiene as described in Table 7. Forty-two percent of household respondents said they drink the water just as it comes from the source without any treatment, while 58% said they do not. When asked why the respondents did something to the water prior to drinking it, the most common response was because it was "contaminated with germs". Participants from KM 100 had the largest proportion (57%) of respondents with this answer. Other common answers were that the water "looked bad" or it was "contaminated with garbage". Very few people suggested that the water was "contaminated with feces" or "smelled bad". Over a third of respondents overall gave some other reason for why they treated their water. Of these, 23% (Jayaco Arriba) was the lowest proportion and 50% (KM 100) was the highest proportion of households that provided various other answers.

Table 7: Reasons for not drinking household drinking water as it comes from the source reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Drink water as it comes		**Reason for not drinking water as it comes**						
Village	Yes N(%)	No N(%)	Contaminated with feces N(%)	Contaminated with germs N(%)	Contaminated with garbage N(%)	Smells bad N(%)	Looks bad N(%)	Other reason N(%)	Don't know/ no response N(%)
Brisas del Yuna	25(51)	24(49)	2(4.1)	7(14)	3(6.1)	0	3(6.1)	12(25)	0
Jayaco Arriba	12(39)	19(61)	3(9.7)	9(29)	6(19)	0	4(13)	7(23)	0
KM 100	3(21)	11(79)	0	8(57)	2(14)	0	3(21)	7(50)	1(7.1)
KM 101	9(43)	12(57)	0	8(38)	4(19)	0	4(19)	6(29)	1(4.8)
KM 103	12(39)	19(61)	2(6.5)	8(26)	3(9.7)	1(3.2)	5(16)	8(26)	0
Majaguay	8(47)	9(53)	0	3(18)	1(5.9)	0	1(5.9)	5(29)	1(5.9)
Total	**69(42)**	**94(58)**	**7(4.3)**	**43(26)**	**19(12)**	**1(0.61)**	**20(12)**	**45(28)**	**3(1.8)**

As depicted in Table 8, when questioned about the believed causes of diarrhea, the largest portion of people thought it was due to drinking unsafe water (48%). Eating contaminated foods, poor hygiene, and parasites were other frequent answers. Very few respondents (only two from Brisas del Yuna and one from KM 101) believed flies were the cause of diarrhea, and thirteen had no answer.

Table 8: Believed causes of diarrhea among household participants reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Believed causes of diarrhea						
Village	Drinking unsafe H2O N(%)	Eating contaminated foods N(%)	Parasites N(%)	Flies N(%)	Poor hygiene N(%)	Other reason N(%)	Don't know/ no response N(%)
Brisas del Yuna	22(45)	16(33)	22(45)	2(4.1)	14(29)	5(10)	3(6.1)
Jayaco Arriba	14(45)	14(45)	11(35)	0	10(32)	2(6.5)	3(9.7)
KM 100	6(43)	4(29)	2(14)	0	6(43)	6(43)	1(7.1)
KM 101	11(52)	7(33)	4(19)	1(4.8)	9(43)	4(19)	3(14)
KM 103	15(48)	12(39)	1(3.2)	0	10(32)	8(26)	3(9.7)
Majaguay	10(59)	7(41)	7(41)	0	4(24)	0	0
Total	**78(48)**	**60(37)**	**47(29)**	**3(1.8)**	**53(33)**	**25(15)**	**13(8)**

Of the 62 primary respondents of the households who said they usually did something to try to prevent diarrhea (Table 9), they typically cited boiling their drinking water, washing their hands, using clean cooking utensils, and eating cooked food (14%, 8%, 4%, and 7%, respectively). Thirty-eight percent of respondents gave some other way to prevent diarrhea and only respondents in KM 103 reported that they did not know how they prevented diarrhea or provided no answer at all. Among all households that boiled their drinking water, Jayaco Arriba had the greatest proportion that did so, while KM 100 had none that did.

Table 9: Methods used for preventing diarrhea reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Try to prevent diarrhea		Methods used to prevent diarrhea*					
Village	Yes N(%)	No N(%)	Boil drinking water N(%)	Wash hands N(%)	Clean cooking utensils N(%)	Eat cooked food N(%)	Other method N(%)	Don't know/ no response N(%)
Brisas del Yuna	16(33)	33(67)	6(12)	2(4.1)	1(2.0)	1(2.0)	9(18)	0
Jayaco Arriba	13(42)	18(58)	8(26)	3(9.7)	3(9.7)	2(6.5)	5(16)	0
KM 100	7(50)	7(50)	0	1(7.1)	1(7.1)	1(7.1)	4(29)	0
KM 101	8(38)	13(62)	3(14)	3(14)	1(4.8)	4(19)	3(14)	0
KM 103	12(39)	19(31)	4(13)	2(6.5)	1(3.2)	2(6.5)	8(26)	2(6.5)
Majaguay	6(35)	11(65)	2(12)	2(12)	0	1(5.9)	6(35)	0
Total	**62(38)**	**101(62)**	**23(14)**	**13(8)**	**7(4.3)**	**11(6.8)**	**35(21)**	**2(1.2)**

* Responses are not mutually exclusive

When prevention methods did not work and someone in the household had diarrhea, equal proportions of households stated they used either herbal or modern medicine as treatment (Table 10). Others reported going either to a health clinic, a private practice, or the hospital. Majaguay had the greatest proportion (65%) of households that relied on herbal medicine and the smallest proportion (41%) that used modern medicine. KM 103 and Majaguay were the only communities that had households that visited a health clinic, and Brisas del Yuna, KM 100 and KM 103 were the only ones to visit a hospital when someone became ill with diarrhea. Even though proportions varied, every community made use of private practices for treating diarrhea.

Table 10: Methods households reported to treat diarrhea during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Methods used to treat diarrhea*					
Village	Herbal medicine N(%)	Modern medicine N(%)	health clinic N(%)	Visit hospital N(%)	Visit private practice N(%)	Other method N(%)
Brisas del Yuna	28(57)	22(45)	0	2(4.1)	7(14)	1(2.0)
Jayaco Arriba	17(55)	17(55)	0	0	6(19)	0
KM 100	7(50)	8(57)	0	4(29)	2(14)	0
KM 101	8(38)	14(67)	0	0	2(9.5)	1(4.8)
KM 103	11(35)	15(48)	3(9.7)	4(13)	2(6.5)	1(3.2)
Majaguay	11(65)	7(41)	1(5.9)	0	1(5.9)	0
Total	**82(50)**	**83(51)**	**4(2.5)**	**10(6.1)**	**20(12)**	**3(1.8)**

* Responses are not mutually exclusive

Data for water quality measures were averaged for each community and are presented in Table 11. Overall the community with the highest geometric mean of total coliforms was KM 101, 2.75 $\log_{10}$ MPN/100mL or 562 MPN/100mL, while Jayaco Arriba had the lowest (2.61 $\log_{10}$ MPN/100mL or 461 MPN/100mL). Jayaco Arriba also had the lowest average $\log_{10}$ *E. coli* level for the entire study compared to Brisas del Yuna which had the highest. Turbidity levels were quite varied, with Majaguay having the lowest average NTUs (0.91) and Brisas del Yuna having the greatest (3.92 NTUs). As expected, *E. coli* contamination levels in each community were significantly lower than total coliform levels (overall average 500 MPN total coliforms/100mL compared to 14 MPN *E. coli*/100mL).

Table 11: Geometric mean of total coliform, *E. coli*, and turbidity levels for each community during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Log$_{10}$ Total Coliforms/100mL				**Log$_{10}$ *E. coli* /100mL**				**Turbidity***			
Community	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%
Brisis del Yuna	2.74	0.92	467	29	1.32	1.10	467	29	3.92	7.62	464	28
Jayaco Arriba	2.61	0.97	310	19	1.00	0.93	310	19	1.64	1.44	310	19
KM 100	2.71	0.83	159	10	1.30	0.85	159	10	2.12	2.85	159	10
KM 101	2.75	0.84	204	12	1.13	0.86	204	12	2.06	2.68	204	13
KM 103	2.71	0.84	338	20	1.02	1.05	338	20	1.83	2.14	337	21
Majaguay	2.69	0.76	156	10	1.13	0.84	156	10	0.91	0.82	156	9
Total	**2.7**		**1634**	**100**	**1.15**		**1634**	**100**	**2.36**		**1630**	**100**

* Responses are missing

After examining all of the beliefs and reported practices for each of the six communities involved in the studies, along with their overall water quality, it was important to see if there were any generalizations that could be made from their weekly *E. coli* levels (Figure 2). Jayaco Arriba had the most consistent levels, while KM 100 had the greatest amount of fluctuation throughout the study. Even though KM 100 had the greatest proportion of participating households that reported treating their drinking water, they still had some of the highest *E. coli* concentrations. Brisas del Yuna and KM 100 often had the highest *E. coli* concentrations, while Jayaco Arriba and KM 103 typically had the lowest levels of contamination. The communities of KM 101 and KM 100 both had very large increases in their *E. coli* concentrations during week seven of the study, and the prior week KM 103 had the largest increase among all communities through the whole study. All communities except for Brisas del Yuna experienced a decrease of some magnitude in *E. coli* concentrations between weeks five and six. Some communities did not have *E. coli* data for all of the weeks and week four was omitted from the graph due to insufficient data.

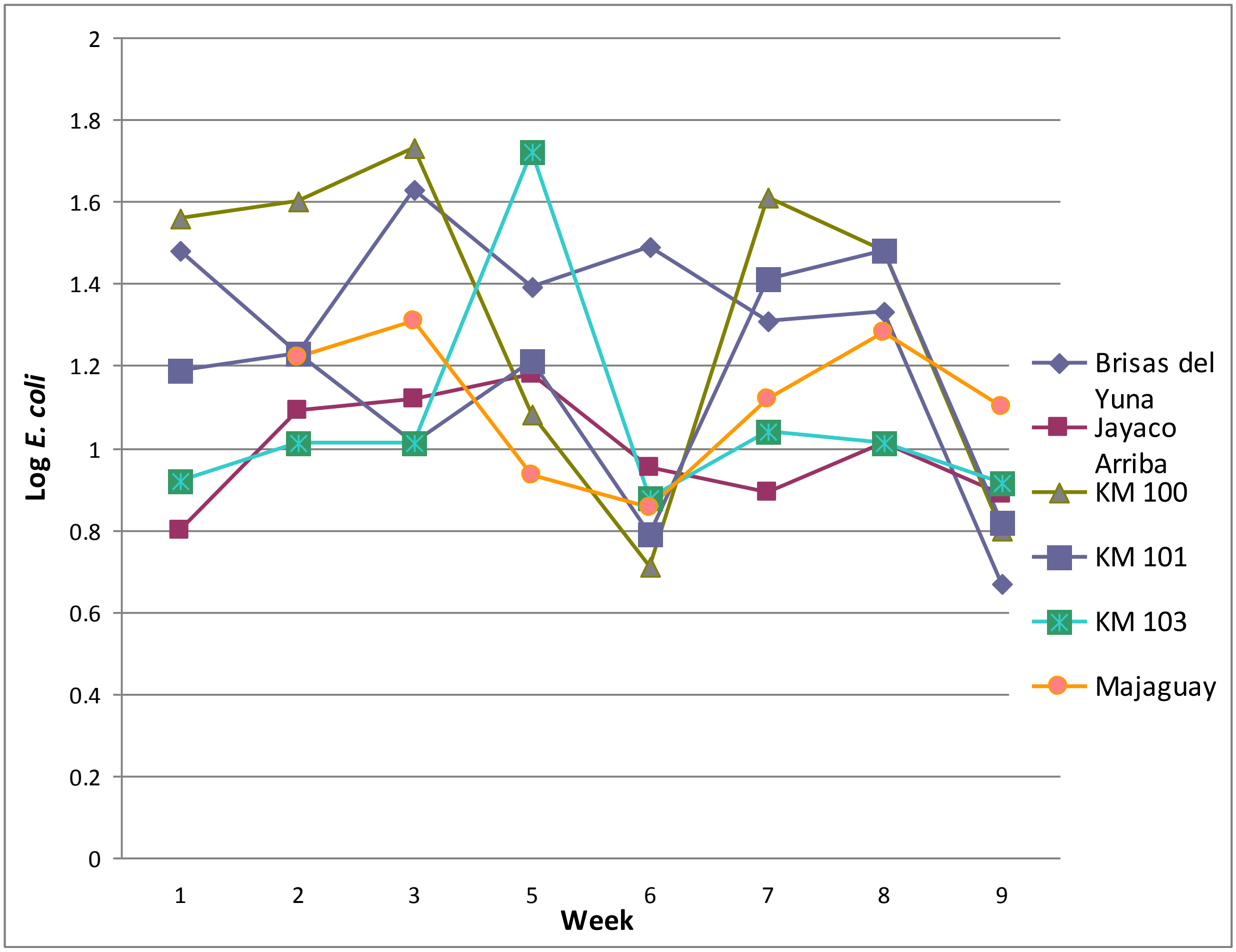


Figure 2: Geometric mean of *E. coli* for each community by week during prospective cohort in Bonao, Dominican Republic 2005-2006.

4.3 Access to sanitation and associated practices

Access to sanitation is important when considering possible mechanisms of contamination of drinking water stored in households. The data shown in Tables 12 and 13 are a summary of access to sanitation and associated practices in participating households in the study. Almost three quarters of participants reported using a private latrine, and some communities had more than 80% of homes with access to private latrines, including Brisas del Yuna, KM 103 and Majaguay. The second most widespread facility used was a shared latrine. Fewer households reported having access to a private flush toilet, while even fewer utilized a shared flush toilet or some other facility.

Table 12: Places households in each community reported were used the restroom during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Place used for the restroom*				
Village	Shared latrine N(%)	Private latrine N(%)	Shared flush toilet N(%)	Private flush toilet N(%)	Other place N(%)
Brisas del Yuna	8(16)	40(82)	0	1(2.0)	1(2.0)
Jayaco Arriba	7(23)	20(65)	0	4(13)	0
KM 100	5(36)	9(64)	0	1(7.1)	0
KM 101	7(33)	11(52)	1(4.8)	2(9.5)	0
KM 103	3(9.7)	25(81)	0	3(9.7)	0
Majaguay	3(18)	14(82)	0	0	0
Total	**33(20)**	**119(73)**	**1(0.61)**	**11(6.8)**	**1(0.61)**

* Responses are not mutually exclusive

When asked about hand washing practices, most commonly (84%) respondents declared that everyone in their household washes their hands after every time they used the bathroom, as indicated in Table 13. Only five people said that no one ever washed their hands after using the restroom. The remaining 21 individuals claimed that the people residing in their homes washed their hands occasionally. The use of soap and water for hand washing was widespread among most of the interviewees. Nearly all reported using soap and water only, and four people claimed they used some other method to clean their hands after relieving themselves. Of the 131 people who claimed they kept soap within the home, only 111 of those could actually produce soap for the interviewer to see.

Table 13: Hand washing practices after using the restroom reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Hands washed after using			**Washed hands with***		
Village	Yes, everyone all the time N(%)	Sometimes, not everyone all the time N(%)	No N(%)	Water only N(%)	Soap and water N(%)	Something else N(%)
Brisas del Yuna	39(80)	8(16)	2(4.1)	13(27)	35(71)	0
Jayaco Arriba	25(81)	5(16)	1(3.2)	6(19)	24(77)	0
KM 100	13(93)	1(7.1)	0	3(21)	11(79)	0
KM 101	18(86)	3(14)	0	8(38)	13(62)	2(9.5)
KM 103	28(90)	2(6.5)	1(3.2)	10(32)	20(65)	2(6.5)
Majaguay	14(82)	2(12)	1(5.9)	5(29)	12(71)	0
Total	**137(84)**	**21(13)**	**5(3.1)**	**45(28)**	**115(71)**	**4(2.5)**

* Responses are not mutually exclusive

4.4 Stored drinking water

Water collection

Overall water quality

Households were visited once every two weeks and drinking water samples were collected. During collection, the respondents were asked to provide the following information: source of water, whether or not it had received any treatment, type of storage container and if another container was used to deliver the water to the sample collection bag. Geometric mean concentrations of total coliforms and *E. coli*, and turbidity are shown in Figures 3 through 6.

These figures are histograms based on the distribution of *E. coli* and total coliforms for all drinking water samples for the entire study. Total coliform $\log_{10}$ measurements ranged from 0 to 3.38 MPN/100mL (3.38 was the upper detection limit of the assay). The histogram appears to be normally distributed (Figure 3), but would not have been if the samples measuring 3.38 $\log_{10}$ MPN/100mL were not removed (as shown in Figure 4). For total coliforms, there was a high proportion of the samples that had >2419.6 total coliforms/100mL (the upper detection limit of the assay). When those values were removed, the data appeared more normally distributed as shown below in the figures.

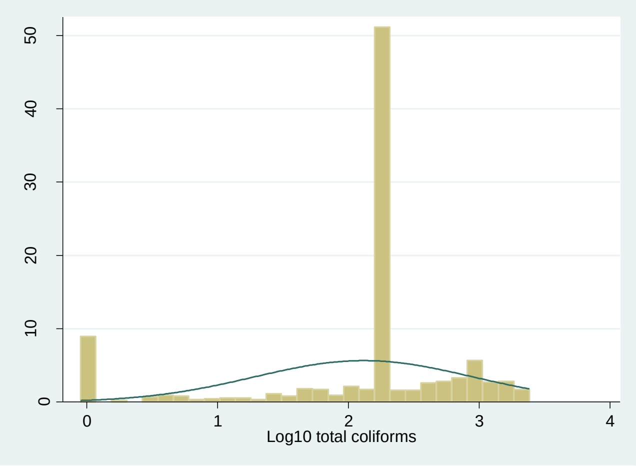


Figure 3: Percent distribution of the Log_{10} MPN/100mL of total coliforms with all upper detection limit counts removed during prospective cohort in Bonao, Dominican Republic 2005-2006.

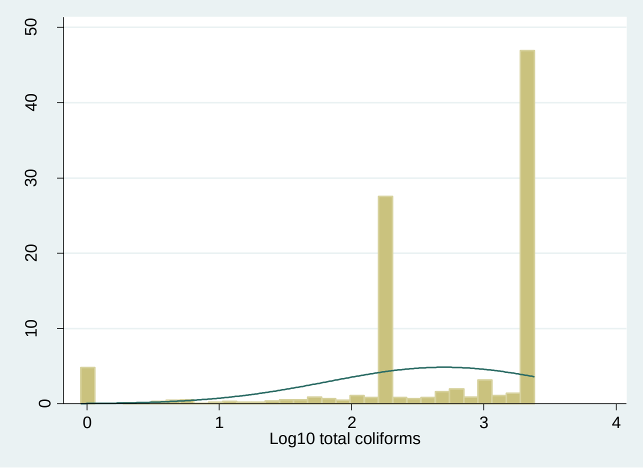
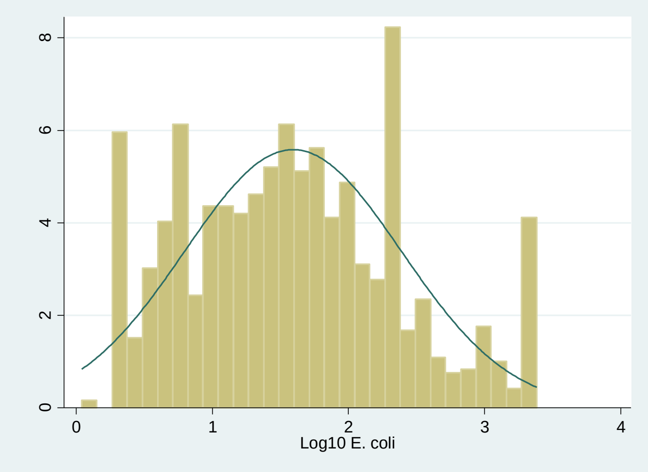


Figure 4: Percent distribution of the Log_{10} MPN/100mL of total coliforms with all upper detection limit counts included during prospective cohort in Bonao, Dominican Republic 2005-2006.

Assay measurements of *E. coli* concentrations ranged from <1 MPN/100mL to 2419.6 MPN/100mL. Similarly to the total coliform measurements and as shown in Figure 6, the lower detection limit of the data was common in about 16% of the samples and this skewed the distribution. If those values were removed, the data appeared more normally distributed as shown in Figure 5, and the greatest percentage of samples had a $\log_{10}$ value of 2.39 MPN/100mL or 245 MPN/100mL.



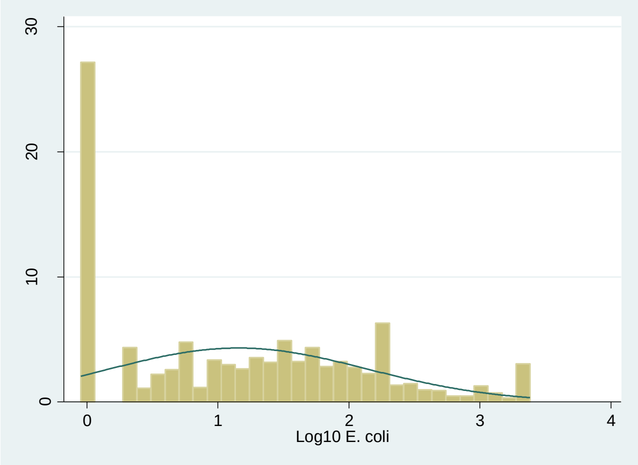


Figure 5: Percent distribution of the Log_{10} MPN/100mL of *E. coli* with all lower detection limit counts removed during prospective cohort in Bonao, Dominican Republic 2005-2006.

Figure 6: Percent distribution of the Log_{10} MPN/100mL of *E. coli* with all lower detection limit counts included during prospective cohort in Bonao, Dominican Republic 2005-2006.

Water source

During the cross-sectional survey, respondents between the six communities provided a variety of answers when asked where they typically retrieve water for their household. Most commonly water was said to be collected from water-taps located outside of the home and second most frequently from a well. Other common answers were from sources such as rivers, springs, and rainwater. Bottled water was also a very popular supply source. Data on reported sources of household drinking water are shown below (Table 14).

Table 14: Sources used for collection of drinking water collection reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Sources for drinking water collection							
Village	River N(%)	Well N(%)	Canal N(%)	Spring N(%)	Rainwater N(%)	Tap inside N(%)	Tap outside N(%)	Bottled water N(%)
Brisas del Yuna	48(98)	24(49)	49(100)	38(78)	49(100)	49(100)	21(43)	45(92)
Jayaco Arriba	30(97)	21(68)	31(100)	30(97)	30(97)	21(68)	15(48)	25(81)
KM 100	14(100)	12(86)	11(79)	14(100)	14(100)	13(93)	2(14)	11(79)
KM 101	18(86)	21(100)	20(95)	21(100)	20(95)	20(95)	3(14)	11(52)
KM 103	22(71)	16(52)	30(97)	29(94)	21(68)	31(100)	27(87)	18(58)
Majaguay	13(76)	3(18)	17(100)	15(88)	17(100)	17(100)	14(82)	17(100)
Total	**145(89)**	**97(60)**	**158(97)**	**147(90)**	**151(93)**	**151(93)**	**82(50)**	**127(78)**

* Responses are not mutually exclusive

As shown in Tables 15 and 16 are data collected from the weekly home visits. This information included the collection sources along with the presence or absence of total coliforms and *E.* coli as well as the turbidity nephelometric units (NTUs) associated with each source. A total of 1634 samples were processed and analyzed over the four months from September 2005 to January 2006. However, during one week, data are missing for one household and therefore a total of 1634 samples were considered in the initial analysis.

Of the total samples, 1,370 of 1,634 samples had *E. coli* present at concentrations at least ≥ 1 MPN/100mL. The greatest number of samples was collected from piped water sources and the smallest proportion of samples was gathered from the river, but those from the river had the highest *E. coli* levels (Figure 7). Other sources for drinking water included wells, springs, bottled water and rainwater.

Total coliform levels were high for each source and many of the samples had so many total coliforms that the upper detection limit of the assay (> 2419.6 MPN/100mL) was met. The *E. coli* counts, on the other hand, were very low for many samples and some even had < 1 *E. coli* MPN/100mL. Average *E. coli* contamination levels were lowest in rain and bottled water as shown in Figure 7. Turbidity fluctuated greatly between the different sources, with averages reaching as low as 0.97 NTUs for bottled water and up to 3.96 NTUs for water from the river. Data on a total of 50 drinking water sample sources were not available and responses were missing for turbidity because there was only sufficient water to test for *E. coli* and total coliforms for four of the samples.

Table 15: Number and percentage of samples from each source with or without *E. coli* present during a prospective cohort in Bonao, Dominican Republic 2005-2006.

	E. coli		
Source	Absent N(%)	Present N(%)	Total
Pipe	97(14)	585(86)	682
Well	62(15)	358(85)	420
Rainwater	47(27)	130(73)	177
Spring	9(12)	68(88)	77
Bottled water	41(23)	137(77)	178
River	0	50(100)	50
Missing	8(16)	42(84)	50
Total	**264(16)**	**1,370(84)**	**1,634**

Table 16: Geometric mean of total coliform, *E. coli*, and turbidity levels for each water source during prospective cohort in Bonao, Dominican Republic 2005-2006.

	Log$_{10}$ Total Coliforms/100mL				**Log$_{10}$ *E. coli* /100mL**			**Turbidity***			
Source	Avg.	Std. dev.	N	%	Avg.	Std. dev.	%	Avg.	Std. dev.	N	%
Pipe	2.75	0.893	682	42	1.37	0.962	42	3.53	5.46	680	42
Well	2.66	0.852	420	26	1.12	0.971	26	1.22	1.81	420	26
Rainwater	2.52	0.962	177	11	0.606	0.784	11	1.58	1.82	177	11
Spring	2.73	0.744	77	4.7	1.18	0.952	4.7	2.58	10.6	76	4.7
Bottled water	2.69	0.855	178	11	0.671	0.844	11	0.97	1.87	179	11
River	3.15	0.443	50	3.1	2.32	0.797	3.1	3.96	2.51	49	3.1
Missing	2.6	1.06	50	3.1	1.01	1.02	3.1	1.78	1.53	49	3.1
Total	**2.7**		**1634**	**100**	**1.16**		**100**	**2.36**		**1630**	**100**

* Responses are missing

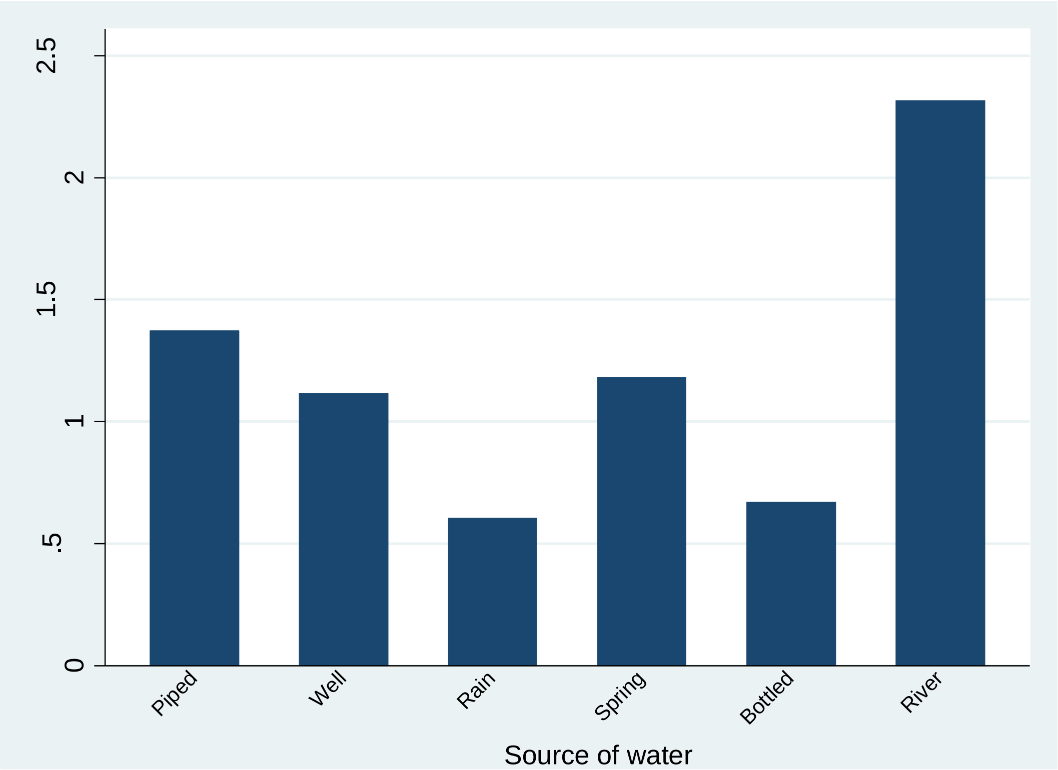


Figure 7: Geometric mean of Log$_{10}$ MPN/100mL *E. coli* by water source during prospective cohort in Bonao, Dominican Republic 2005-2006.

Although *E. coli* levels did fluctuate from week to week, households that drank river water consistently through the length of the study had highest levels of *E. coli* contamination (Figure 8). Bottled and rain water consistently had the lowest contamination levels with average *E. coli* concentrations of 0.67 and 0.61 $\log_{10}$ MPN/100mL (4.6 and 4.0 MPN/100 mL), respectively. Piped water supplies demonstrated the least amount of fluctuation among the sources but was consistently the second most contaminated source compared to river water throughout the study.

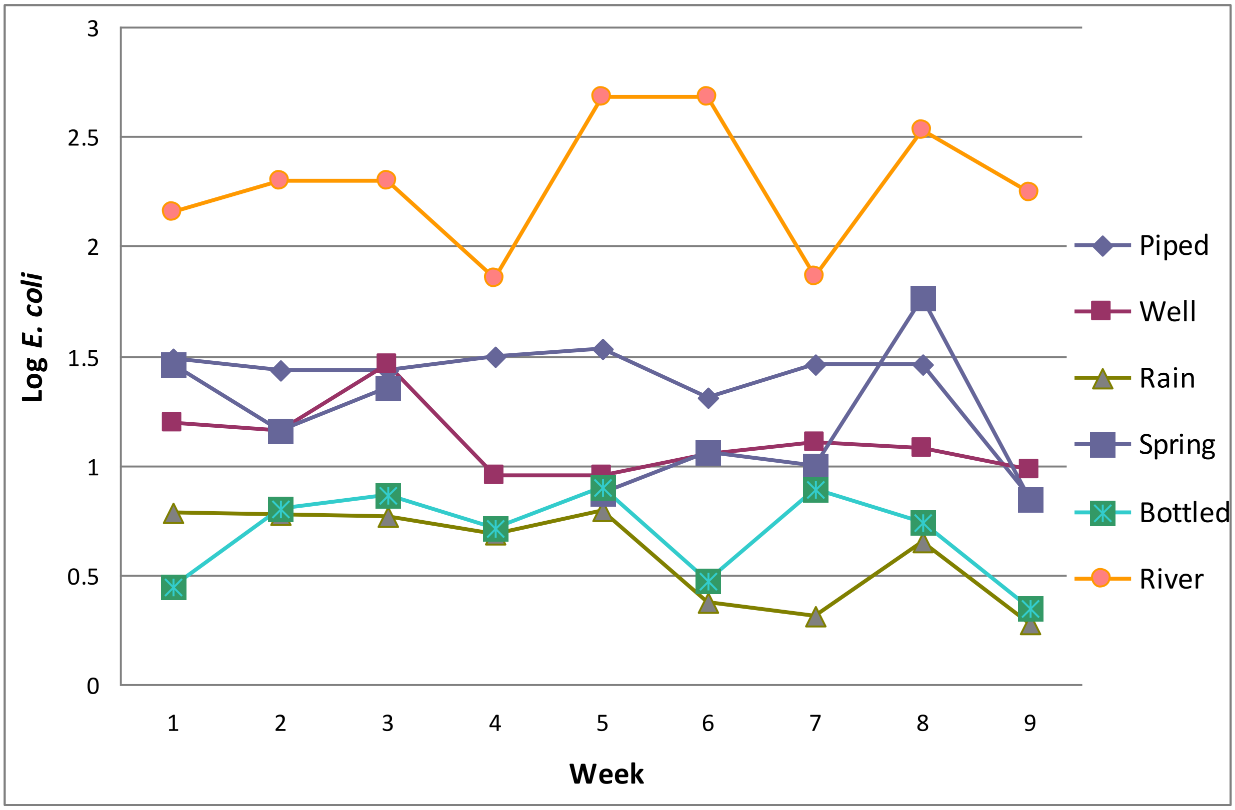


Figure 8: Geometric mean of log *E. coli* for each water source by week during prospective cohort in Bonao, Dominican Republic 2005-2006.

Collection container

Individuals in the study reported using an assortment of collection containers, as well. During the cross-sectional study, a large proportion of households reported using either buckets or gallon containers to collect drinking water (Table 17). Others reported using vessels such as barrels (7.4%) and saucepans (4.3%). Only three households in the study reported gathering water directly from a tap, and this took place in the communities of Brisas del Yuna, KM 101 and Majaguay. The use of pitchers or jugs to collect water was only named by one household (from KM 103) during the survey, and this may have been due to the small size of the container and its inability to hold a large volume of water. An additional 28 household respondents named some other type of container used for water collection. Participating households were also asked to provide a listing of how many of each type of container were available for use in the home, and more than 140 different responses were given (not shown).

Table 17: Collection container usage reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Collection container*						
Village	Bucket N(%)	Gallon jug N(%)	Barrel or drum N(%)	Jar or jug N(%)	Sauce pan N(%)	Directly from tap N(%)	Other N(%)
Brisas del Yuna	40(82)	38(78)	0	0	0	1(2.0)	6(12)
Jayaco Arriba	21(68)	20(65)	3(9.7)	0	0	0	5(16)
KM 100	13(93)	12(86)	1(7.1)	0	0	0	3(21)
KM 101	17(81)	14(67)	2(9.5)	0	1(4.8)	1(4.8)	6(29)
KM 103	23(74)	10(32)	5(16)	1(3.2)	4(13)	0	8(26)
Majaguay	13(76)	13(76)	1(5.9)	0	2(12)	1(5.9)	0
Total	**127(78)**	**107(66)**	**12(7.4)**	**1(0.61)**	**7(4.3)**	**3(1.8)**	**28(17)**

* Responses are not mutually exclusive

Depending on their individual needs, households collected water at varying frequencies according to responses given during the cross-sectional study. As shown in Table 18, more than half of the population (59%) described gathering water as frequently as seven times a week. Three and four times a week were the next most frequent responses. KM 101 was the only community to have households report collecting water six or eight times a week. When drinking water samples were collected during the longitudinal study it was observed that the type of container the households had used to collect water each week often varied from what was indicated in the initial cross-sectional survey.

Table 18: Frequencies for collection of drinking water reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	How many times drinking water is collected each week							
	0	1	2	3	4	5	7	8
Village	N(%)	N(%)	N(%)	N(%)	N(%)	N(%)	N(%)	N(%)
Brisas del Yuna	1(2.0)	1(2.0)	9(18)	7(14)	0	0	31(63)	0
Jayaco Arriba	0	1(3.2)	3(9.7)	6(19)	0	0	21(68)	0
KM 100	0	0	2(14)	2(14)	1(7.1)	0	9(64)	0
KM 101	1(4.8)	1(4.8)	4(19)	1(4.8)	1(4.8)	1(4.8)	10(48)	2(9.5)
KM 103	0	3(9.7)	9(29)	5(16)	3(9.7)	0	11(35)	0
Majaguay	0	0	1(5.9)	2(12)	0	0	14(82)	0
Total	**2(1.2)**	**6(3.7)**	**28(17)**	**23(14)**	**5(3.1)**	**1(0.61)**	**96(59)**	**2(1.2)**

Water storage

Storage container

By examining the cross-sectional questionnaire, water management after collection was assessed. A variety of practices were documented but the most common was that people either choose to transfer their water to some other container for storage within the household, or to leave it where it was until consumption. The questionnaire also revealed that several different types of containers were reported to be used for storing and serving household drinking water. As shown in Table 19, over half of the households (66%) replied that they stored their drinking water in gallon containers (shown in Figure 9). The second most commonly used storage container was a bucket (26%). Other containers described being used as storage vessels were clay pots, saucepans, barrels or drums, and jars or jugs. An additional 14% of people used 5-gallon plastic bottles, the type of bottles that are placed on water coolers (see Figure 10). Brisas del Yuna was the only community that reported storing water in saucepans.

Table 19: Type of containers used to store household drinking water reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Storage container*									**Container water stored in**		
Village	Bucket N(%)	Gallon N(%)	Barrel or drum N(%)	Clay pot N(%)	Sauce pan N(%)	Jar or jug N(%)	Bottles N(%)	gallon jug N(%)	Other N(%)	Same as collection N(%)	Different from collection N(%)	Both, in collection and other N(%)
Brisas del Yuna	18(37)	36(73)	0	0	1(2.0)	0	2(4.1)	6(12)	2(4.1)	35(71)	16(33)	0
Jayaco Arriba	8(26)	18(58)	0	2(6.5)	0	1(3.2)	2(6.5)	5(16)	6(19)	15(48)	14(45)	0
KM 100	5(36)	13(93)	0	2(14)	0	0	0	1(7.1)	1(7.1)	9(64)	7(50)	0
KM 101	4(19)	12(57)	0	0	0	3(14)	1(4.8)	6(29)	3(14)	10(48)	5(24)	6(29)
KM 103	5(16)	14(45)	3(9.7)	3(9.7)	0	4(13)	1(3.2)	5(16)	3(9.7)	9(29)	18(58)	3(9.7)
Majaguay	3(18)	14(82)	1(5.9)	1(5.9)	0	2(12)	1(5.9)	0	0	8(47)	11(65)	0
Total	**43(26)**	**107(66)**	**4(2.5)**	**8(4.9)**	**1(0.61)**	**10(6.1)**	**7(4.3)**	**23(14)**	**15(9.2)**	**86(53)**	**71(44)**	**9(5.5)**

* Responses are not mutually exclusive

When questioned regarding why household respondents chose drinking water storage containers, a wide array of answers was given (Table 20). The two most common answers were that the containers were "convenient" and they "prevented contamination". Household respondents from KM 103 appeared to be more concerned about preventing contamination than those in other communities. Other answers included qualities about the containers like they were cheap (20%), easily available (19%), and easy to use (27%). Very few people suggested that their vessels were chosen because they were strong or sturdy.

Table 20: Reasons reported for choosing containers used for storage reported during cross-sectional interview in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Reason for choosing storage container*						
Village	Prevent contamination N(%)	Easily available N(%)	Cheap N(%)	Convenient N(%)	Easy to use N(%)	Sturdy/ strong N(%)	Other reason N(%)
Brisas del Yuna	20(41)	9(18)	11(22)	28(57)	12(24)	0	4(8.2)
Jayaco Arriba	13(42)	5(16)	8(26)	19(61)	4(13)	0	5(16)
KM 100	2(14)	2(14)	2(14)	8(57)	5(36)	1(7.1)	3(21)
KM 101	9(43)	9(43)	6(29)	12(57)	10(48)	1(4.8)	4(19)
KM 103	15(48)	5(16)	5(16)	12(39)	9(29)	0	6(19)
Majaguay	5(29)	1(5.9)	1(5.9)	10(59)	4(24)	0	3(18)
Total	**64(39)**	**31(19)**	**33(20)**	**89(55)**	**44(27)**	**2(1.2)**	**25(15)**

* Responses are not mutually exclusive

The containers that households reported using for storage during the preliminary cross-sectional questionnaire differed from what was observed during the weekly household visits. Table 21 shows actual container usage throughout the study, along with descriptions of each container. Figures 9-13 are pictures of actual containers used by participating households for storage of drinking water. There can be several variations of each type of container, but they are still classified together because they have the same basic characteristics. For example, a gallon jug can be a regular milk jug or they can be some sort of other plastic container, like those that hold cooking oil (Figure 9).

Figure 9: Sample being poured from gallon jug ("gallon")

Figure 10: 5 gallon jug ("botellon") on top of various other containers

Figure 11: Barrel ("barrica") kept outside of the home

Figure 12: Water being served from pitcher (“jarron”) with a cup (“taza”)

Figure 13: Variety of household collection & storage containers

Table 21: Container descriptions and their usage in numbers and proportions during prospective cohort study in Bonao, Dominican Republic 2005-2006.

Container	Description	N(%)	Mouth	Size
No container		10(0.61)		
Gallon jug	Typically a plastic milk jug	858(53)	Narrow	Small
5 gallon jug	Plastic jug that fits on water cooler	158(9.7)	Narrow	Large
2 liter	Soda bottle	16(0.98)	Narrow	Small
Pot	Cooking dish	99(6.1)	Wide	Small
Pitcher	Plastic or metal pitcher	64(3.9)	Wide	Small
Bucket	Typically a plastic bucket	311(19)	Wide	Large
Clay pot	Typically tall with smooth edges	39(2.4)	Wide	Large
Barrel/ drum	Typically a stationary metal drum	21(1.3)	Wide	Large
Tank	Typically a stationary concrete box	16(0.98)	Wide	Large
Other	Cups, saucepans, etc.	41(2.5)	Varied	Varied
Missing		1(0.06)		
Total		**1,634**		

The data in Table 22 demonstrate the frequency of drinking water storage containers that were found during household drinking water sampling. Gallon jugs were by far the most commonly used storage container (53%), and were most often associated with water gathered from either well or piped sources. The river was the least common source used for collection of household drinking water, but when it was used the largest proportion (14%) of it was stored in either clay pots or barrels. Two liter containers were predominantly used to store piped water.

Table 22: Number of times a type of storage container was used in association with each source during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Source							
Container	Piped N(%)	Well N(%)	Rain N(%)	Spring N(%)	Bottled N(%)	River N(%)	Missing N(%)	**Total N**
No container	7(70)	3(30)	0	0	0	0	0	**10**
Gallon jug	390(46)	253(30)	86(10)	48(5.8)	47(5.7)	10(1.2)	24(2.8)	**858**
5 gallon jug	22(14)	21(14)	9(5.8)	2(1.3)	101(65)	0	3(1.9)	**158**
2 liter	12(75)	2(12.5)	2(12.5)	0	0	0	0	**16**
Pot	43(43)	28(30)	10(11)	4(4.3)	9(10)	0	5(5.1)	**99**
Pitcher	28(44)	14(24)	8(14)	3(5.1)	5(8.5)	1(1.7)	5(7.8)	**64**
Bucket	145(47)	78(26)	32(11)	14(4.6)	4(1.3)	31(10)	7(2.3)	**311**
Clay pot	11(28)	4(11)	12(32)	5(14)	0	5(14)	3(5.1)	**39**
Barrel/ drum	7(33)	4(19)	7(33)	0	0	3(14)	0	**21**
Tank	3(19)	4(27)	8(53)	0	0	0	1(6.3)	**16**
Other	14(34)	8(21)	3(7.7)	1(2.6)	13(33)	0	2(4.9)	**41**
Missing	0	1(100)	0	0	0	0	0	**1**
Total	**682(42)**	**420(26)**	**177(11)**	**77(4.9)**	**179(11)**	**50(3.2)**	**49(3.0)**	**1634**

Based on data from the cross-sectional survey, over half of the respondents indicated that they use the same container to store and collect drinking water. Forty-three percent reported using some vessel other than what the water was initially collected in, and another 5% said they fluctuate between using either the same or different containers (not shown).

Water quality

The WHO's objective for bacteriological quality of drinking water is zero *E. coli* per 100 ml, even during emergencies or disasters[58]. Out of the 1634 water samples collected throughout this study, only 264 had < 1 *E. coli* MPN/100mL water. The presence or absence of *E. coli* was determined for all water samples and was stratified by container, as shown in Table 23.

Table 23: Number and percentage of samples from each container with or without *E. coli* during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	E. coli		
Container	Absent N(%)	Present N(%)	**Total**
No container	1(10)	9(90)	**10**
Gallon jug	154(18)	703(82)	**857**
5 gallon jug	34(22)	124(78)	**158**
2 liter	4(25)	12(75)	**16**
Pot	18(18)	81(82)	**99**
Pitcher	12(19)	52(81)	**64**
Bucket	26(8.4)	285(92)	**311**
Clay pot	0	39(100)	**39**
Barrel/ drum	1(4.8)	20(95)	**21**
Tank	3(19)	13(81)	**16**
Other	11(27)	30(73)	**41**
Missing	0	2(100)	**2**
Total	**264(16)**	**1,370(84)**	**1,634**

The water samples were not tested only for the presence or absence of *E. coli*, but also for the actual level of contamination and these measures were calculated by the MPN method. As seen in Figure 14, out of all of the collection containers, on average, clay pots and buckets had the highest levels of contamination. On the other hand, the 5 gallon jugs had the lowest average levels of *E. coli*.

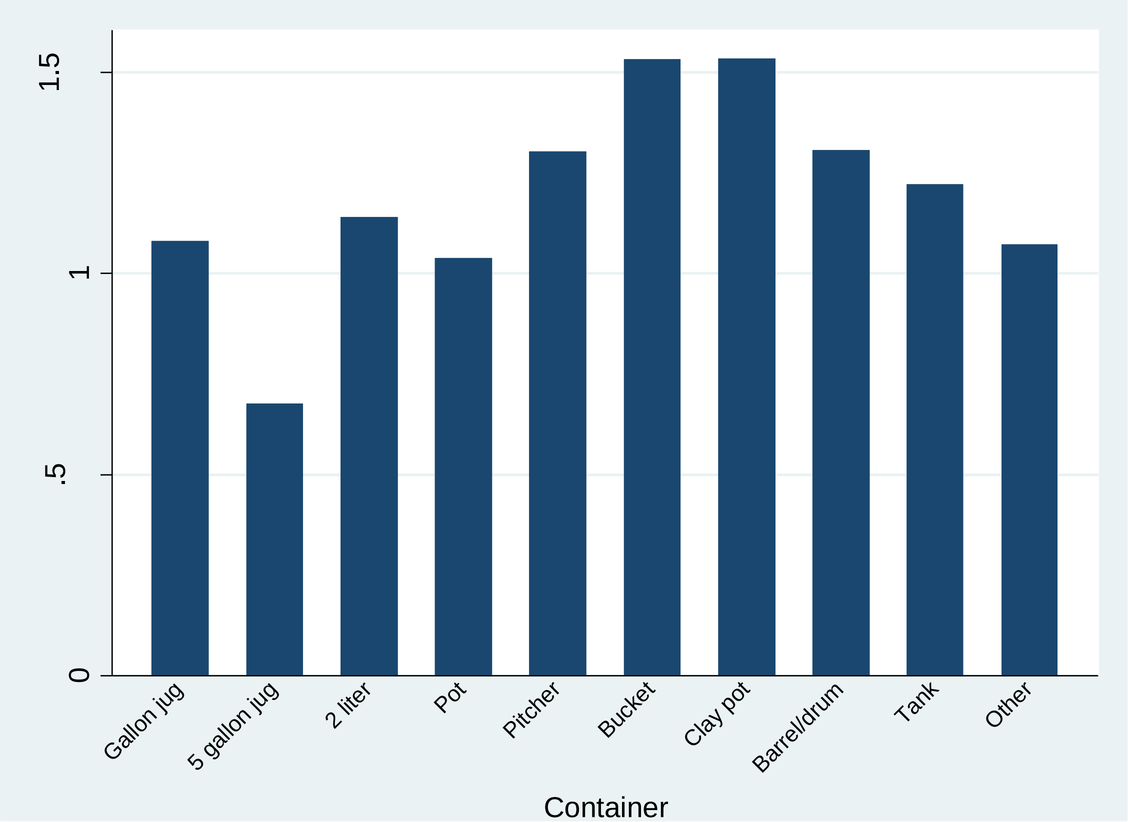


Figure 14: Geometric mean of *E. coli* stratified by container during prospective cohort in Bonao, Dominican Republic 2005-2006.

Along with testing *E. coli* levels every week, total coliforms and turbidity were checked for each container as well (Table 24). Clay pots and barrel/ drums appeared to have the highest concentrations of total coliforms, while tanks had the least. The type of container with a much higher turbidity than all others was the two liter at an average turbidity of 3.7 NTUs. Ten other samples were not from storage containers, but they were still included in these tables in order to show all samples. Five gallon jugs seemed to have the least amount of turbidity overall.

Table 24: Geometric mean of total coliform, *E. coli*, and turbidity levels for each container type during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Log$_{10}$ Total Coliforms/100mL				Log$_{10}$ *E. coli* /100mL				Turbidity*			
Container	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%
No container	2.84	0.663	10	0.61	1.92	1.12	10	0.61	9.93	20.6	10	0.61
Gallon jug	2.7	0.842	857	52	1.08	0.944	857	52	2.62	5.06	855	52
5 gallon jug	2.55	0.959	158	9.7	0.676	0.839	158	9.7	0.855	0.907	158	9.7
2 liter	2.74	0.972	16	0.98	1.14	1.21	16	0.98	3.7	6.25	16	0.98
Pot	2.7	0.946	99	6.1	1.04	0.964	99	6.1	2.26	2.93	99	6.1
Pitcher	2.77	0.918	64	3.9	1.3	1.04	64	3.9	3.04	7.74	63	3.9
Bucket	2.75	0.907	311	19	1.53	1.03	311	19	2.21	1.95	311	19
Clay pot	2.97	0.484	39	2.4	1.53	0.784	39	2.4	1.43	1.22	39	2.4
Barrel/ drum	2.93	0.811	21	1.3	1.31	0.966	21	1.3	2	1.71	21	1.3
Tank	2.15	1.06	16	0.98	1.22	0.996	16	0.98	1.48	0.962	16	0.98
Other	2.56	1.06	41	2.5	1.07	1.12	41	2.5	2.05	2.67	41	2.5
Missing	3.38	0	2	0.12	3.05	0.474	2	0.12	6	.	1	0.06
Total	**2.7**		**1634**	**100**	**1.19**		**1634**	**100**	**2.3**		**1630**	**100**

* Responses are missing

When looking at contamination levels independently by water source and storage container, *E. coli* levels varied greatly and no patterns of contamination were established. Since the water source and the type of storage container may play roles in the levels of contamination of drinking water, the two characteristics were examined together in order to determine any correlations (not shown). River water was the most contaminated water source for every container that was used to collect it, and rainwater and bottled water consistently had the lowest *E. coli* levels.

The data in Table 25 is a representation of the proportion of drinking water samples sorted by container and source that are classified into each risk category as proposed by Lloyd and Helmer[59]. River water, compared to all other sources, had the highest proportion (70%) of drinking water samples in the group with the highest magnitude of contamination, while rain water had the smallest proportion of samples in this risk group. Inversely, rain water had the greatest proportion of its samples grouped at the lowest magnitude of risk and river samples had the lowest proportion for the same group. The data in Table 26 indicates that among all of the containers, those with the highest proportion of samples in the <1 *E. coli* MPN/ 100mL grouping were the five gallon jug, two liter bottle and other category (22%, 25% and 27%, respectively). Thirty-six percent of bucket samples were grouped into the grossly polluted risk group, and this was a higher proportion than all other containers.

Table 25: Proportion of drinking water samples for each risk category, by source during prospective cohort study in Bonao, Dominican Republic 2005-2006.

		Source Proportion (%) of samples according to risk category					
E. coli cfu/100ml	Risk	Piped	Well	Rain	Spring	Bottled	River
<1	No risk	14	15	27	12	23	0
1-10	Low risk	20	35	47	33	46	8
11-100	Intermediate to high risk	39	28	19	31	22	22
>100	Gross pollution: high to very high risk	27	22	7	24	9	70
		100	**100**	**100**	**100**	**100**	**100**

Table 26: Proportion of drinking water samples for each risk category, by container during prospective cohort study in Bonao, Dominican Republic 2005-2006.

		Container Proportion (%) of samples according to risk category									
E. coli cfu/100ml	Risk	Gallon jug	5 gallon jug	2 liter bottle	Pot	Pitcher	Bucket	Clay pot	Barrel/ drum	Tank	Other
<1	No risk	18	22	25	18	19	9	0	5	19	27
1-10	Low risk	31	46	19	39	19	23	31	35	19	24
11-100	Intermediate to high risk	33	23	37	24	29	32	45	30	43	22
>100	Gross pollution: high to very high risk	18	9	19	19	33	36	24	30	19	27
		100	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Container opening

Previous studies have indicated that the size of a storage container's opening may affect the levels of contamination found in the water being stored[33, 43]. Interviewers were asked to characterize the size of the opening of the drinking water storage containers. These classifications were made based on the diameter of the container opening, with anything less than about two inches being designated as narrow-mouthed, and anything greater than that a wide- mouthed container. Interviews indicated that about half of the containers had narrow openings (49%), as shown in Table 27. Brisas del Yuna and KM 101 had the largest proportion of households using all narrow-mouthed containers for storage of water, and KM 103 had the greatest proportion of households using all wide-mouthed vessels. Forty-six out of 163 responses acknowledged that they had both wide and narrow-mouthed vessels designated for storage within their household. The smallest proportion of participants reported the use of all wide-mouthed containers.

Table 27: Reported household usage of wide- and narrow-mouthed storage containers during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Mouth of storage containers		
Village	All wide N(%)	All narrow N(%)	Both wide & narrow N(%)
Brisas del Yuna	11(23)	28(57)	13(27)
Jayaco Arriba	10(32)	10(32)	9(29)
KM 100	0	9(64)	5(36)
KM 101	3(14)	13(62)	5(24)
KM 103	12(39)	11(35)	7(23)
Majaguay	2(12)	8(47)	7(41)
Total	**38(23)**	**79(49)**	**46(28)**

Shown in Figure 15 is the geometric mean of *E. coli* for both narrow- and wide-mouthed storage containers. Narrow-mouthed containers had an average of 10.5 *E. coli* per 100mL water, while those that were wide-mouthed had a mean of 25.1 *E. coli* per 100mL water. A t-test revealed there was a significant difference between the effect wide- and narrow-mouthed containers on *E. coli* concentrations in household drinking water. No significant difference was determined for average total coliforms or turbidity in regards to container opening size.

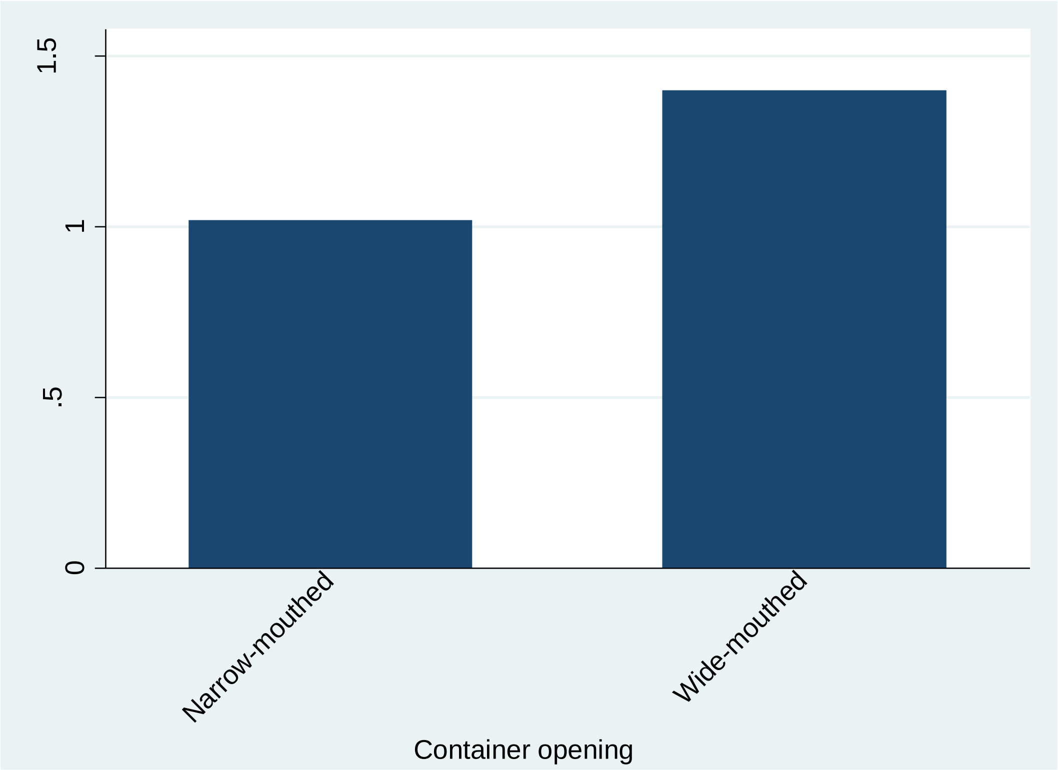


Figure 15: Geometric mean of *E. coli* for containers with either narrow or wide-mouthed openings during prospective cohort study in Bonao, Dominican Republic 2005-2006.

Wide- and narrow-mouthed openings were also sorted into risk groups based on the levels of *E.* coli contamination and the results are displayed in Table 28 and Figure 16. The greatest proportion of samples fit into the low risk category (1-10 *E. coli* MPN/100mL) for narrow- and wide-mouthed storage containers, 33% and 27%, respectively. Narrow-mouthed vessels had the smallest proportion of samples grouped into the highest level of contamination. Wide openings on containers also had a higher percentage of samples that would be considered grossly polluted (31% compared to 17% for narrow).

Table 28: Proportion of drinking water samples for each risk category, sorted by container opening during prospective cohort study in Bonao, Dominican Republic 2005-2006.

		Container opening Proportion (%) of samples according to risk category	
E. coli cfu/100ml	Risk	Narrow	Wide
<1	No risk	19	11
1-10	Low risk	33	27
11-100	Intermediate to high risk	31	31
>100	Gross pollution: high to very high risk	17	31
		100	**100**

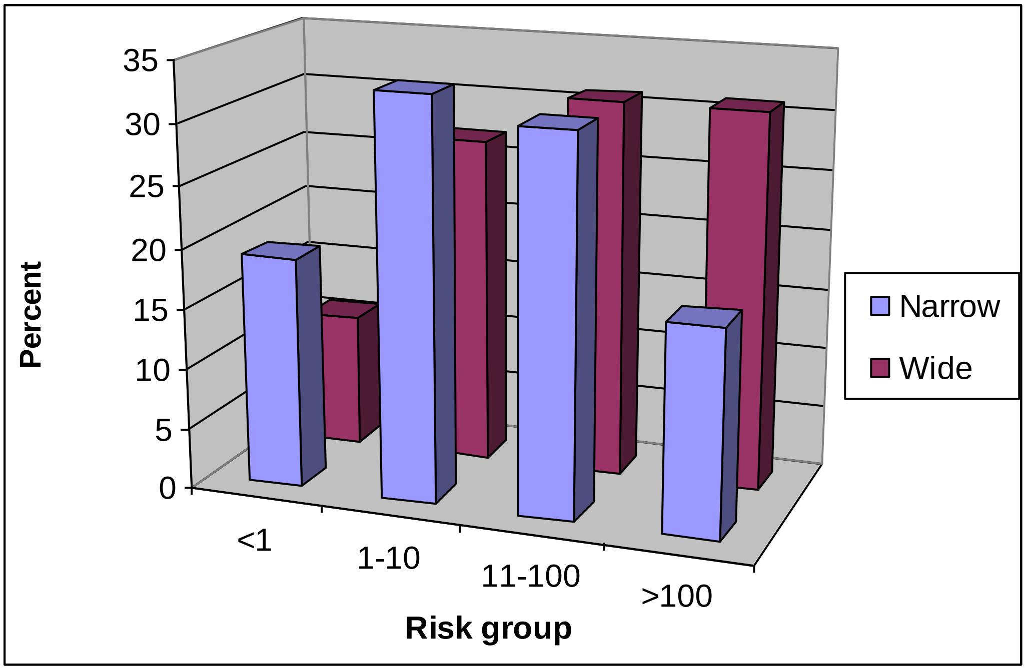


Figure 16: Proportions of samples from narrow and wide-mouthed containers by risk group during prospective cohort study in Bonao, Dominican Republic 2005-2006.

There are distinct differences between the narrow- and wide-mouthed containers when comparing the averages of the log transformed *E. coli* levels, and once the groups are stratified by MPN *E. coli* groups[59], the differences are still present. The stratification as shown in Figure 16 better indicates the distribution of *E. coli* concentrations between the two types of openings. The majority water samples collected from narrow-mouthed containers had *E. coli* concentrations that fit into the two lowest risk groups (<1 and 1-10 MPN/100mL).

Water serving method

In addition to the opening size on a storage container affecting contamination levels, the method of removing water from it has been associated with fecal contamination as well[5, 43, 60]. Since the majority of storage containers were indicated to be narrow-mouthed, it makes sense that over 60% of participants reported during the cross-sectional survey that no utensil was necessary to remove drinking water, but instead poured the water straight from the container. This is due to the inability to place any sort of instrument through the opening of containers with small diameters. Jars were by far the most common tool used to dip drinking water out of the storage container when a utensil was utilized. Cups, bowls and buckets were used sparingly for this particular task. On three occasions some other method or retrieving water from the storage container was described. Table 29 represents the proportion of each type of serving method reported for each of the six communities during the initial cross-sectional questionnaire. No one reported dipping water directly out of the storage container with their hands.

Table 29: Types of utensils used to serve water out of storage container reported during cross-sectional survey in prospective cohort in Bonao, Dominican Republic 2005-2006.

	Utensil used for dipping and serving water*					
Village	Pour directly from container N(%)	Cup N(%)	Jar N(%)	Bowl N(%)	Bucket N(%)	Other N(%)
Brisas del Yuna	39(80)	0	16(33)	0	0	1(2.0)
Jayaco Arriba	21(68)	0	13(42)	1(3.2)	0	1(3.2)
KM 100	9(64)	0	8(57)	0	0	0
KM 101	16(76)	1(4.8)	10(48)	0	0	0
KM 103	18(58)	3(9.7)	16(52)	0	1(3.2)	0
Majaguay	15(88)	0	4(24)	0	0	1(5.9)
Total	**118(72)**	**4(2.5)**	**67(41)**	**1(0.61)**	**1(0.61)**	**3(1.8)**

* Responses are not mutually exclusive

Water quality was analyzed and stratified based on the usage of a dipping device or not to serve water to the sample collection bag during the nine sample collection periods (Table 30). Both geometric means for total coliform and *E. coli* levels were higher for households that used some utensil to serve drinking water. Turbidity, on the other hand, was lower in these households. The higher levels of contamination could be due to members of the household contaminating the water with soiled hands when retrieving water from the vessel. Two sample t-tests suggested a significant difference in average total coliform and *E. coli* concentrations between households who did use a serving utensil and those who did not. However, this practice would be commonly associated with a large opening container and may be too highly correlated to determine if the effect is the result of the utensil or the larger opening.

Table 30: Water quality based on the use or disuse of a serving utensil during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	$\log_{10}$ Total Coliforms/100mL				$\log_{10}$ *E. coli* /100mL				Turbidity*			
Served with	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%
No utensil	2.67	0.894	1078	66	1.04	0.967	1078	66	2.58	5.44	1074	66
Utensil	2.76	0.85	556	34	1.37	1	556	34	1.93	1.75	556	34
Total	**2.7**		**1634**	**100**	**1.15**		**1634**	**100**	**2.36**		**1630**	**100**

* Responses are missing

Container volume

Associations have been made in previous studies between *E. coli* levels and the volume of the container the drinking water is held in[5, 43, 60]. To examine this without our data, we stratified drinking after storage containers into two sizes: large – which would be approximately four gallons or more and small – less than four gallons. These volume classifications were based on the average amount of water a household consumes in one day versus the amount of drinking water that may be stored for multiple days. The geometric averages of *E. coli* concentrations were 1.27 $\log_{10}$ MPN/100mL (18.6 MPN/100mL) for samples in larger volume containers, compared to 1.09 $\log_{10}$ MPN/100mL (12.3 MPN/100mL) for those that had been held in smaller vessels (Figure 17). These concentrations, once compared in a t-test, indicated that there was a significant difference between drinking water samples that had been stored in either small or large volume containers. When mean total coliforms were examined based on container volume, there was no significant difference.

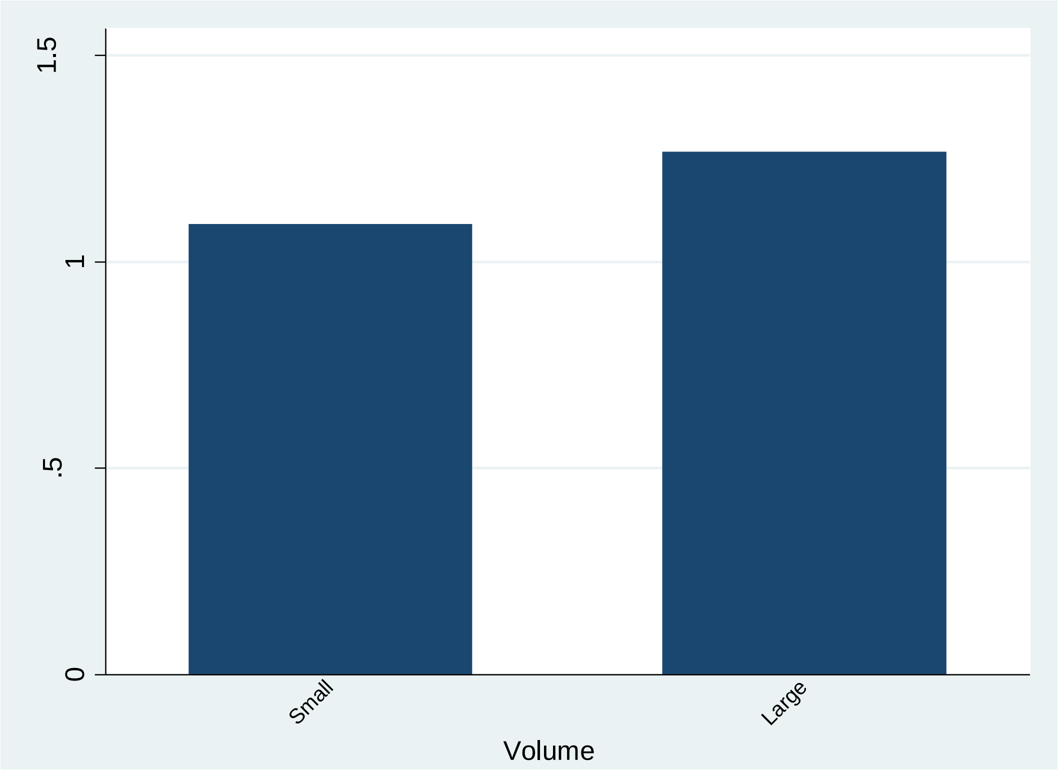


Figure 17: Geometric mean of *E. coli* levels in water samples, by storage container volume during prospective cohort study in Bonao, Dominican Republic 2005-2006.

Household water drinkers

Part of the cross-sectional questionnaire also asked how many people in each household was drinking water from the storage container and these results are displayed in Table 31. The greatest number of drinkers given was 36, but the most common answer was five people. The greatest proportion (71%) of drinkers per household ranged from three to six people. Unexpectedly, four people stated that no one drank from their stored water. Water quality data from the longitudinal was averaged and compared with the number of people indicated during the initial cross-sectional survey in order to determine any possible associations. Arriba and KM 101 were the only communities that had more than ten people drinking from their household supply of stored drinking water. Not so unexpectedly, the household with 36 people drinking from the same stored water source had the highest geometric mean of *E. coli* levels (2.3 MPN/100mL). While at the same time, households with the fewest number of people drinking from the storage container had the lowest *E. coli* concentrations.

Table 31: Number of people in household that drink stored water, by community reported during cross-sectional study in prospective cohort study in Bonao, Dominican Republic 2005-2006, along with the *E. coli* levels associated with those numbers.

	Number of people in household drinking water from storage container												
Village	0 N(%)	2 N(%)	3 N(%)	4 N(%)	5 N(%)	6 N(%)	7 N(%)	8 N(%)	9 N(%)	10 N(%)	>10 N(%)		
Brisas del Yuna	1(2.0)	2(4.1)	4(8.1)	12(24)	11(22)	9(18)	3(6.1)	4(8.2)	2(4.1)	1(2.0)	0		
Jayaco Arriba	0	1(3.2)	5(16)	8(26)	8(26)	5(16)	2(6.5)	0	1(3.2)	0	1(3.2)		
KM 100	0	0	2(14)	4(29)	3(21)	4(29)	1(7.1)	0	0	0	0		
KM 101	2(9.5)	0	2(9.5)	1(4.8)	4(19)	6(29)	2(9.5)	2(9.5)	0	0	2(9.5)		
KM 103	0	1(3.2)	7(23)	5(16)	5(16)	3(9.7)	2(6.5)	5(16)	2(6.5)	0	0		
Majaguay	1(5.9)	0	0	3(18)	3(18)	2(12)	3(18)	2(12)	3(18)	0	0		
Total	**4(2.5)**	**4(2.5)**	**20(12)**	**33(20)**	**34(21)**	**29(18)**	**13(8)**	**13(8)**	**8(4.9)**	**1(0.61)**	**4(2.5)**		
	0	2	3	4	5	6	7	8	9	10	11	18	36
Log E. coli	0.8	0.57	1	1.2	1.1	1.2	1.6	1.3	1.3	1.3	1.6	1.5	2.3
Std. dev.	0.92	0.54	0.84	0.92	0.76	0.87	0.87	0.98	0.78		1.1		

Treatment

Treating drinking water that was gathered from an unprotected source seems like the best method of preventing illness by eliminating contamination and was commonly reported among households in the study. As shown in Table 32, greater than 500 water samples collected during the study were reported to have been treated; yet only 142 of those had < 1 *E. coli* MPN/100mL. Oddly, almost just as many untreated samples had no *E. coli* present. Unfortunately in this study, *E. coli* was still present even after treatment, and in some instances the treatment did not lower the contamination levels. Even under these variations, a significant difference was observed between the geometric mean of *E. coli* levels in treated and untreated samples, and the same was true for average total coliforms.

Table 32: Number of samples based on treatment status with or without *E. coli* present during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	E. coli		
Treated	Absent N(%)	Present N(%)	**Total**
No	122(11)	1,002(89)	**1,124**
Yes	142(28)	366(72)	**508**
Missing	0	2(100)	**2**
Total	**264(16)**	**1368(84)**	**1,634**

Forty-one percent of respondents said in the cross-sectional questionnaire that they typically transfer their water from the container used for collection to another one before treating it, as shown in Table 33. Jayaco Arriba, KM 100, KM 103 and Majaguay were the communities who regularly chose this method over another. Only two people reported not specifically treating in one type of container or another, but instead alternating between the collection container and something else. The remaining 33% never treat their water in anything other than the container it was gathered in.

Table 33: Container water was treated in reported during cross-sectional survey in prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Container water treated in*			
Village	Same as collection N(%)	Different from collection N(%)	Both, in collection and other N(%)	Doesn't know/ no response N(%)
Brisas del Yuna	17(35)	15(30)	0	17(35)
Jayaco Arriba	8(26)	16(52)	0	9(29)
KM 100	7(50)	9(64)	0	0
KM 101	10(48)	5(24)	1(4.8)	5(24)
KM 103	9(29)	14(45)	0	8(26)
Majaguay	2(12)	8(47)	1(5.9)	6(24)
Total	**53(33)**	**67(41)**	**2(1.2)**	**45(28)**

* Responses are not mutually exclusive

In regards to household water treatment, answers provided during the cross-sectional questionnaire varied significantly from the practices observed during the longitudinal study. Households that reported boiling or chlorinating their drinking water during the cross-sectional questionnaire were compared to those who actually did provide treated water samples during the weekly visits (Table 34). Some households that reported this practice early on did provide treated water samples throughout the study, however, it was a low percentage. Only 35% of households that initially reported treating their water by boiling and 20% by chlorinating actually provided samples during the longitudinal study that had been treated. Several households reported in the initial survey that they did not chlorinate of boil their stored drinking water, but during the water quality testing provided treated samples. For households that did not initially report this practice, approximately 15% of samples from these households were treated by boiling and 4% by chlorination.

Table 34: Household treatment practices - reported vs. actual during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Actually boiled				**Actually chlorinated**		
Reported	No N(%)	Yes N(%)	Missing N(%)	**Total**	No N(%)	Yes N(%)	**Total**
Yes	403(65)	214(35)	1(0.16)	**617**	234(80)	58(20)	**292**
No	727(85)	128(15)	0	**855**	1,128(96)	53(4)	**1,181**
Missing	122(75)	39(24)	1(0.62)	**162**	156(96)	5(3.1)	**161**
Total	**1,252(77)**	**342(23)**	**2(0.12)**	**1,634**	**1,362(92)**	**111(8)**	**1,634**

Since approximately 18% of the samples collected during the study were reported to be subjected to some type of treatment (boiling or chlorination), it was important to look at the effects of different treatment methods used in the communities (Table 35). The most widespread method of treating the water mentioned both in the questionnaire and during household drinking water sample collection was boiling. Following that, chlorination was the most common technique used to disinfect drinking water. Almost just as many people, who named chlorination as their choice treatment, indicated that buying bottled water was the best method to ensure safe drinking water. Only two individuals stated that they filtered their water, and another twelve named some other method of decontaminating their drinking water. Overall, boiling, chlorination and other methods or treatment had the same basic effect on the geometric mean *E. coli* counts (0.85, 0.85 and 0.83 $\log_{10}$ MPN/100mL, respectively).

Table 35: Water quality for each treated vs. untreated drinking water samples during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Log$_{10}$ Total Coliforms/100mL				**Log$_{10}$ *E. coli* /100mL**				**Turbidity***			
Treatment	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%	Avg.	Std. dev.	N	%
No	2.77	0.771	1124	69	1.29	0.973	1124	69	2.19	4.5	1123	69
Yes	2.54	1.07	508	31	0.849	0.962	508	31	2.74	4.63	506	31
Missing	3.38	0	2	0.12	2.62	1.08	2	0.12	3.2	.	1	0.06
Total	**2.7**		**1634**	**100**	**1.15**		**1634**	**100**	**2.36**		**1630**	**100**

* Responses are missing

	Logtc			**Logec**			**Turbidity***		
Method	Avg.	Std. dev.	N	Avg.	Std. dev.	N	Avg.	Std. dev.	N
Boiled**	2.72	0.899	380	0.846	0.978	380	3.01	5.14	378
Chlorinated**	1.96	1.36	116	0.848	0.935	116	2.03	2.51	116
Other**	2.87	0.891	18	0.829	0.715	18	1.24	0.892	18
Total	**2.55**		**514**	**0.846**		**514**	**2.73**		**512**

** Responses are not mutually exclusive

Shown in Figure 18 is a comparison of geometric mean *E. coli* /100mL levels between treated and untreated household drinking water samples. The data are categorized by the collection source of water. Bottled water was the only source that had higher *E. coli* levels in the treated samples compared to untreated water. This was most likely attributable to the water being of good quality to begin with and then contamination occurring after the point of collection and treatment but prior to use. Samples that were originally gathered from a piped source showed the greatest improvement in water quality after being treated. The geometric average *E. coli* for all untreated samples was 1.29 $\log_{10}$ MPN/ 100mL (std. dev. = 0.97) or 19.5 *E. coli* MPN/100mL and for all treated samples was 0.85 $\log_{10}$ MPN/100mL (std. dev. = 0.96) or 7 *E. coli* MPN/100mL. When categorized by source, the river had the highest log *E. coli* levels from both treated and untreated samples (about 1.96 and 2.34 $\log_{10}$ MPN/ 100mL, respectively). Rain water had the lowest geometric mean of *E. coli* levels overall for treated samples, and for untreated samples the lowest concentrations were from bottled and rain water.

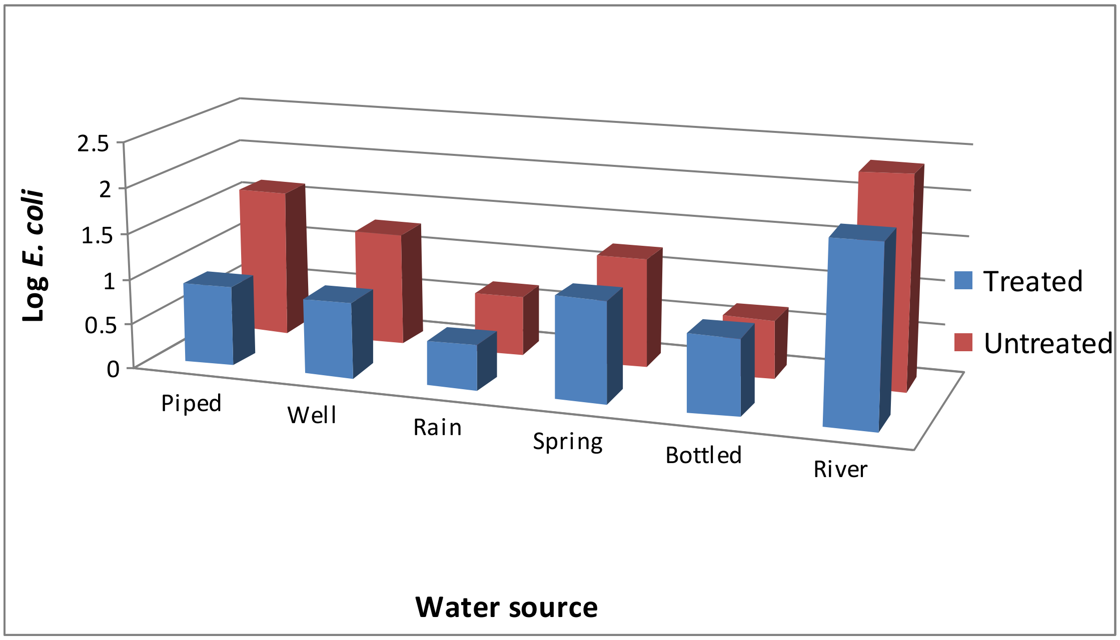


Figure 18: Geometric mean of log *E. coli* in treated and untreated samples by source during prospective cohort study in Bonao, Dominican Republic 2005-2006.

Even though many of the samples had been treated, they still had *E. coli* present, and this is shown in Figure 19. Among all of the untreated samples, the two liters had the greatest levels of contamination, with pitcher and bucket following closely behind. On average, the five gallon jugs had the least amount of *E. coli* contamination across both the treated and untreated samples, and at the same time there was not much difference between the two groups. The lack of variation between the treated and untreated samples stored in five gallon jugs was most likely due to the majority of these samples being bottled water. Clay pots and barrels had the highest levels of contamination between all of the treated water samples

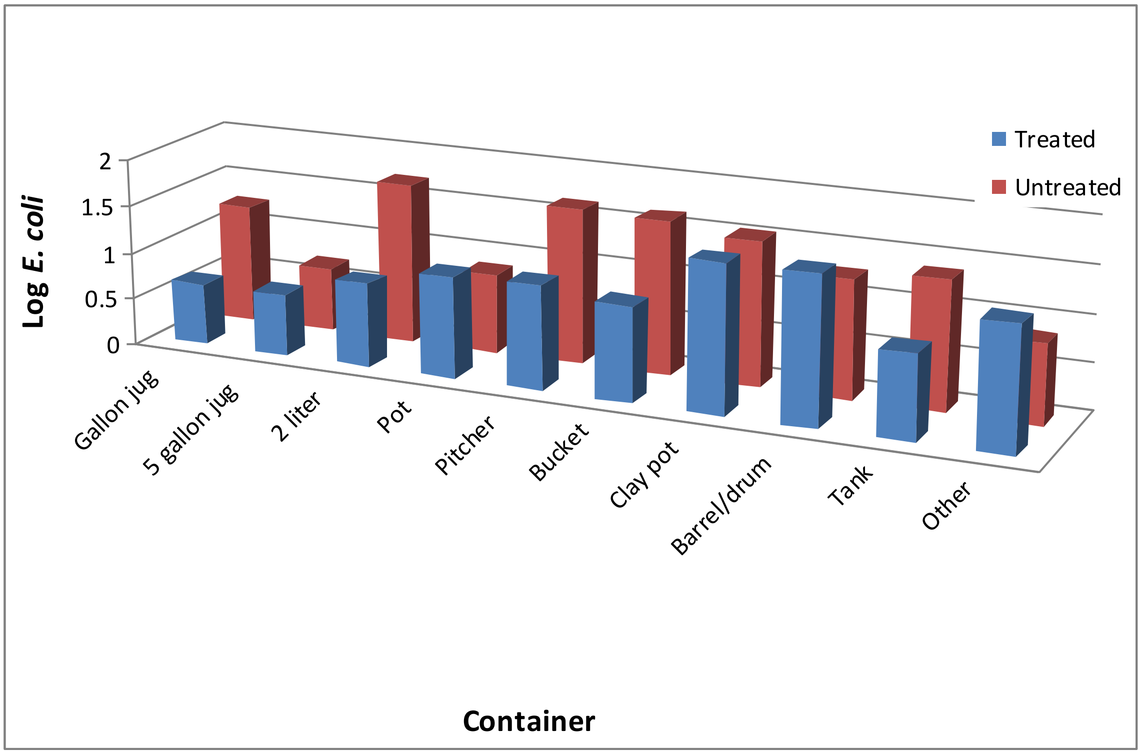


Figure 19: Geometric mean of *E. coli* in treated and untreated samples by container during prospective cohort study in Bonao, Dominican Republic 2005-2006.

As expected, a difference in the geometric mean *E. coli* concentrations between treated and untreated drinking water samples was significant by two sample t-test. There was an average of 19.5 MPN/100mL of *E. coli* in untreated water, compared to 7.06 MPN/100mL in treated water across all sources and containers.

Statistical test results

Table 36 shows the p values for the associations between various measures of water quality and the potential risk factors discussed earlier. The community a household belonged to had a significant effect on both *E. coli* and turbidity levels. Treating stored household drinking water had a statistically significant impact on all aspects of the water quality except for total coliform counts. Use of a utensil, type of storage container and source of drinking water were all potential risk factors that had significant impacts on every measure of water quality. Significance was seen for both arithmetic and geometric means of *E. coli* MPN when examining the size of household storage container opening and volume. Method of serving water, either pouring or dipping, may explain the some of the p values calculated for turbidity. Container opening size had the least statistical significance when it came to turbidity, and this may be attributed to having to pour the water out of narrow-mouthed vessels, which may keep particles suspended. The opposite may true for container volume, which had the greatest correlation with turbidity. It is a possibility that the larger the container is, the more particulates settle at the bottom of the container and are less likely to be resuspended during serving.

Table 36: P values of significance for various measures of water quality and potential risk factors during prospective cohort study in Bonao, Dominican Republic 2005-2006.

	Measures of water quality*				
Potential risk factors	Total coliform MPN/100mL N=1634	Total coliform Log_{10} MPN/100mL N=1634	*E. coli* MPN/100mL N=1634	*E. coli* Log_{10} MPN/100mL N=1634	Turbidity NTU N=1630
Community	0.0873	0.0931	**0.0001**	**0.0001**	**0.0001**
Type of container	**0.0473**	**0.0442**	**0.0001**	**0.0001**	**0.0001**
Source of water	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Narrow or wide container opening	**0.0073**	0.1065	**< 0.001**	**< 0.001**	0.5667
Small or large container volume	0.4211	0.8328	**0.0019**	**0.0007**	**0.0001**
Use or no use of utensil	**0.0355**	**0.0470**	**0.0002**	**< 0.001**	**0.0056**
Treated or not	0.0783	**< 0.001**	**0.0167**	**< 0.001**	**0.0235**

* Non-parametric values were found by Kruskal-Wallis equality-of-populations rank test

CHAPTER V: DISCUSSION AND CONCLUSION

5.1 Discussion

Lack of access to improved water and sanitation, along with hygiene has led to epidemics of diarrheal disease, especially in tropical developing countries[33]. In rural areas of the Dominican Republic, like those in this study, drinking water is often collected from both improved and unimproved sources, and then stored within the household before consumption. This allows for multiple opportunities for fecal contamination between the collection source and point of use of the drinking water[17, 33, 43]. Our study, like others, focused primarily on *E. coli* levels because even though the log values for total coliforms were significantly greater than those for *E. coli* and indicate much more elevated levels of contamination, their importance is typically of lesser value because total coliforms are not as indicative of risk[17, 33, 61].

Storage container

Several conclusions about household drinking water storage can be drawn from this study. First, comparisons of average *E. coli* concentrations by storage container type indicated that using wide-mouthed and also large volume containers increased the likelihood of fecal contamination, regardless of source. Narrow-mouthed vessels had significantly lower *E. coli* levels, proportion of samples with *E. coli* and more samples that were free of *E. coli* compared to wide mouth opening storage containers. Therefore, narrow-necked containers were to some extent capable of protecting or maintaining current levels of *E. coli* levels in the stored household drinking water by minimizing contamination possibilities. Other studies have also found narrow-mouthed containers to have significantly better water quality and a potentially protective effect in terms of *E. coli* contamination, but were often done on a much smaller scale[43, 48-49]. In cases of extreme fecal pollution, it had been previously observed that there was no difference between wide and narrow openings on storage containers[43]. This study, on the other hand, which had average *E. coli* levels <100 *E. coli*/100mL found the opposite to be true in that there was a significant difference in *E. coli* concentration based on the size of the container opening, even at the highest detectable levels of *E. coli* contamination.

E. coli was still found in narrow-mouthed containers, suggesting that other factors in addition to the size of the opening play a role in fecal contamination of drinking water. Often, if the source of drinking water is of really poor quality, improved means of household treatment and storage may not lead to quantifiable improvements in water quality. For example, Jensen *et al*. determined that not all contamination was prevented by having containers with narrow openings in the household, and this may have been due to extreme levels of contamination originating at the source[43]. Therefore, fecal contamination occurring in the household seems to be of greater importance to the overall quality of the drinking water when the source is relatively uncontaminated. One study indicated that lower levels of *E. coli* contamination in narrow-necked storage containers compared to those with wide openings is likely to be generally attributable to die-off caused by greater heat exposure[62]. However, we were unable to determine if that was the case here since no other environmental factors were measured outside of those reported.

Smaller volume containers also had lower concentrations of *E. coli* concentrations when compared to those with greater volumes in households participating in this study. This may be due in part to the fact that most small volume containers had smaller openings, and therefore the concentrations were more directly correlated with the narrow mouth. In general, the results from this study suggest that fecal contamination of household drinking water can be affected by the characteristics of the container it is stored in. These containers can play a role in protecting water after collection. Contrary to this study, studies completed by Copeland *et al.* and Trevett *et al.* both suggested that the type of storage container was not a major determinant of either the risk for and level of contamination[5, 17]. The Copeland *et al.* data was based on a cross-sectional study, which was done in Brazil and included 297 households. Each household only had their drinking water quality tested once during the study and the households utilized fewer types of containers than were included in our study. Different drinking water sources was another contrasting aspect of these studies[5]. On the other hand, the Trevett *et al.* study had just about the same number of participating households as our study and was also conducted longitudinally. The variation of storage containers was very similar to ours, but the sources were not. The only drinking water sources included in the study were hand-dug wells and boreholes, while our study included six different ones[17].

Water storage practices and beliefs

In addition to the role of the household drinking water storage container, other household water management practices were found to impact drinking water quality. For example, practices and beliefs such as serving drinking water with a utensil can also have a deleterious effect on the risk of fecal contamination by allowing hands or other potential fomites to contact the water. Total coliforms and *E. coli* both had higher levels of contamination when a serving utensil was used: however, turbidity did not increase. The significant difference seen in contamination levels between households who dip and households that pour water out of the storage container could be tied to the fact that serving utensils could not be placed through the opening of narrow-mouthed vessels. A possible explanation for the higher turbidity in the households who did not serve water with a utensil could be that direct pouring may have stirred and re-suspended particles that had settled at the bottom of the storage container. Similar studies have determined that dipping water out of the storage container may introduce fecal matter to stored drinking water[5, 17, 46].

Reported sanitation and hygiene practices regarding drinking water handling and storage may have been associated with the contamination levels in the household drinking water. Even though all but a few households reported washing both their water collection and storage containers, there was still contamination of *E. coli* in the water samples. A study done in India implemented a hygiene questionnaire with questions similar to those asked in the preliminary cross-sectional survey, and found an association between low hygiene scores and an increase in fecal contamination in stored water[33]. Many households reported using soap to wash their hands, but not all of those households were able to provide soap for the interviewer to see. This same observation was made in a study conducted in rural Honduras[17]. It has also been suggested that fecal contamination may be inadvertently introduced during the washing of storage containers[5, 17].

Almost all households had access to improved sanitation facilities, but very few of these had access to a flushing toilet, and this may play a role in the contamination of stored household drinking water. A recent study found no statistically significant differences in availability of improved sanitation facilities between households with contaminated and uncontaminated stored water samples[61]. In addition to sanitation and hygiene practices, as in previous studies, we found that the larger the number of people in a household drinking stored water, the greater the levels of *E. coli* contamination found in the water samples[61, 63].

Treatment

Chlorination and boiling were widely utilized methods of treating drinking water in the households that participated in this study in the Dominican Republic and they both reduced the level of total coliforms and *E. coli.* These results correlate with those from other studies on point-of-use water treatment and water quality[33, 56]. As in other studies, even when water was reported to have been treated, microbiological testing indicated that contamination was still present[33, 55, 61]. Some households rely more on filtration, either through cloth sieves or some other filtration device. Biosand filters have recently been introduced into areas in the Dominican Republic as an alternative method of decontaminating household water[57].

5.2 Study Limitations

A major limitation of this study is that the sampling of households was not randomized. Households were chosen for participation based on accessibility of eligible respondents and cooperativeness. A number of households were excluded during the period of the longitudinal study because they no longer had a child under the age of five years. Another limitation was that twenty-two of the households that were not initially included in the study were added after it began. This meant that they did not complete the preliminary questionnaire, which may have altered the statistics based on household demographics, beliefs and reported practices.

There were a few limitations related to water quality measurements. For example, water quality data was not available for the water sources themselves; therefore there were no baseline levels of contamination to compare the point of use water quality. Additionally, *E. coli* and total coliform concentrations in the drinking water at the time of sampling may not be entirely representative of the quality of water consumed by members of the household during the previous two weeks. Previous studies have determined that *E. coli* levels in water may change by orders of magnitude over relatively short periods of time[64]. These changes can be affected by conditions such as temperature, UV exposure, nutrient availability and pH, along with various other factors[64-65].

An added limitation was due to a strike during week four which prevented researchers from traveling to certain communities; therefore they were left out of that week's data collection. Finally, all potential risk factors were not tested together for correlations with *E. coli* or total coliform concentrations.

5.3 Recommendations

When examining drinking water quality, it is imperative to focus prevention efforts not only at the source, but also within the household in order to lessen pathogen transmission. Even though not all samples stored in a narrow-mouthed containers were free of *E. coli,* there appears to be some protective effect of selecting this storage container. It is recommended that more research as well as promotion of the widespread use of narrow-mouthed containers in communities like those in this study could potentially reduce the risk of fecal contamination. It is also important to educate people about the importance of sanitation and hygiene, along with disease transmission routes.

5.4 Conclusion

Although policies and procedures for collection and treatment of water supplies have been established in a majority of countries, these are not always adhered to. As a result, communities are left in jeopardy from waterborne diseases. There has been an increasing prevalence of water related diseases, even in developed countries where water supplies are considered to be of high quality and safe[66]. In developing countries, because of this increase, it is important to implement and promote appropriate and acceptable point-of-use disinfection techniques, along with encouraging safe, sanitary and hygienic household storage practices. There is a pressing need to ensure a safe, reliable and continuous supply of water to protect the health of those in underdeveloped regions.

The WHO's target of zero *E. coli* per 100 mL cannot be reached by improvements at the supply level alone, so interventions at the point of use are necessary. This study is consistent with others in terms of levels of *E. coli* contamination being affected by water collection, storage and use[4, 61]. Even if water at the source meets WHO's water quality standards, it does not necessarily ensure that good water quality will be maintained within the household, unless fecal contamination is prevented both during transport and within the home.

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