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A Baseline Assessment of Water Quality and Access in the Bisate Catchment Area, Rwanda

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2012

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Abstract

A Baseline Assessment of Water Quality and Access in the Bisate Catchment Area, Rwanda

By Anita K. Kambhampati

The Bisate Region of Rwanda presents unique challenges to conservation and public health, as it is home to both the endangered mountain gorilla and a human population of 20,000 individuals. Prior research indicates a potential for disease transmission between humans and gorillas. This study analyzed the water quality in Bisate in order to gain insight into the risks of enteric infection in both the gorillas and human populations in Bisate and the possibility of transmission between these populations. Water samples from eight untreated water points were analyzed over a period of seven weeks. Total coliforms were used as overall indication of water quality, while *Escherichia coli* was used as an indicator for recent fecal contamination, as it does not normally occur in the environment. Of three main water sources inside Volcanoes National Park, only one was found to be consistently free of *E. coli*. All water points connected to this uncontaminated source were also free of *E. coli*, while the other sources and connected water points revealed varying levels of *E. coli* contamination ranging from 1.0 to 362.4 MPN/100 ml. Seven treated water points were tested for free residual chlorine; none of the points met the World Health Organization chlorine standard for piped water distribution. Geospatial mapping of the water sources was conducted in conjunction with a sample of 365 surveyed households to examine the accessibility of the households to improved water sources. While 84.4% of surveyed households were within 1 kilometer of an improved water source, possible barriers to access included the steep topography of the area, poor quality of some water sources, wait times, and user fees. The results of this study indicate that there is a need for greater accessibility to clean and improved water sources, in addition to better promotion of household water treatment to ensure residents are drinking safe water. Increased availability of clean water in the community may discourage residents from using water sources inside Volcanoes National Park. Reduced human activity in the park may decrease the risk of pathogen introduction into water sources as well as the risk of human-animal pathogen transmission.

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Introduction

Despite improvements in the quality and access to water and sanitation, the burden of diarrheal disease persists as a major global health issue. The World Health Organization (WHO) estimates that there are approximately 1.7 billion cases of diarrheal illness annually, with approximately 88 percent of these cases caused by poor water, inadequate sanitation facilities, and improper hygiene [1]. In 2000, the United Nations included water and sanitation as a target in its Millennium Development Goals. The target, 7.C, seeks to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" [2].

In March 2012, the WHO/UNICEF Joint Monitoring Programme for Water and Sanitation (JMP) announced that the target for safe drinking water had been met [3]. However, while the target was met on a global level, most countries on the continent of Africa did not reach the UN goal. Further, over 40 percent of the world's population without access to safe water lives in the countries of sub-Saharan Africa [3].

One of these countries, Rwanda, has made improvements in its water and sanitation infrastructure since its genocide 20 years ago, but it is still struggling to meet the UN target for water. Rwanda is the most densely populated country in the world, with over 12 million people inhabiting slightly over 26,000 square kilometers [4]. It is estimated that only 69 percent of this population has access to an improved water source of any type [5]. Known as the "land of a thousand hills", Rwanda's landlocked location and hilly terrain often cause increased difficulty for people in many areas, especially rural villages, to obtain an adequate quantity of water [6]. Many commonly used water sources are also contaminated by fecal matter and other pollutants [7].

The Bisate Catchment Area, a rural area situated next to Rwanda's Volcanoes National Park, has both limited water supply and poor water quality. While the park has natural sources of water located inside its boundaries, its distinction as a protected ecosystem has led to stringent regulations requiring all persons entering the park to have a permit. Additionally, despite receiving abundant rainfall (about 1,200 millimeters per year) the area's porous volcanic soil absorbs most of the rainwater [8]. As a result, residents of the Bisate Region must rely on various man-made water taps that have been built throughout the community.

Bisate is served primarily by three natural water sources that are located inside Volcanoes National Park: Bunyenyeri Spring, Bushokoro Well, and Myase Stream. Two of these sources, Bunyenyeri and Bushokoro, provide the water for community taps through a series of pipelines. The community taps served by these two sources are free to the public. During the dry season, however, many of the community taps have decreased water supply, further limiting access to water by the residents [9]. The community also has a number of treated water taps managed by the Rwanda Energy, Water, and Sanitation Authority (EWSA). These taps dispense water that is sourced and chlorinated outside Bisate, but residents are charged for their use. At the time of this study, it cost 15 Rwandan francs (approximately US $0.02) to fill one 20 liter jerry can [10].

An interface between two environments, the Bisate Catchment Area serves as a region of unique ecological importance. The area is not only home to approximately 20,000 people but is also one of the few remaining habitats of the endangered mountain gorilla (*Gorilla berengei*) [11]. In 1985, shortly after the death of famed zoologist Dian Fossey, less than 300 of the gorillas existed in the wild, threatened by poachers as well as environmental degradation. Through extensive efforts by conservationists, the gorilla population has more than doubled to 800 today. More than half of these animals live in an area comprised of three national parks located in Rwanda, Uganda, and the Democratic Republic of the Congo, including Volcanoes National Park [12].

However, a new threat has emerged to the gorillas: research has indicated that due to genetic similarities, humans and gorillas may transmit disease-causing agents to each other through means such as fecal-contaminated water [13]. Despite the entry laws, the forest's natural resources, including water, continue to attract villagers inside the park's boundaries. Additionally, the growing tourism industry has led to habituation of the mountain gorilla population to humans, and an increasing number of gorillas have been observed leaving the park [11]. The potential increase in human-animal contact heightens the risk of disease transmission, including diarrheal illness, for both populations. There is a need to analyze the quality of commonly used water sources in Bisate in order to gain information about the levels of fecal contamination in water, the risk of enteric infection for gorillas and humans in the region, as well as the risk of pathogen transmission between the two populations.

This study assessed the quality of community water sources throughout the Bisate Catchment Area, comparing water sources both inside and outside Volcanoes National Park to determine possible origins of contamination. We tested water samples from selected sources for common indicator bacteria of water quality (total coliforms and *Escherichia coli*). Total coliforms refer to a group of gram-negative rod-shaped bacteria that are commonly found in the environment and in the feces of warm-blooded animals. While they do not directly cause illness, total coliforms indicate the efficiency of water treatment, as well as overall water quality [14]. *E. coli* has been used as a indicator of fecal contamination since the late 1800s, and is generally the preferred indicator for this type of contamination [15]. *E. coli* exist in the intestinal tract of humans and other warm-blooded animals. As *E. coli* have a limited survival time outside the body and do not naturally reproduce in the environment, they are considered a reliable indicator of recent fecal contamination [15].

We also analyzed samples from treated water sources to determine whether levels of chlorine are high enough to sustain disinfection throughout piping. Upon initial chlorination of water, the chlorine reacts with metals and organic materials in the water. After these initial reactions, the residual chlorine either reacts with nitrogen in the water to form combined chlorine, or remains free for disinfection [16]. This residual free chlorine is crucial for inactivation of bacteria and other organisms that may enter the water from the pipeline or during transport and household water storage. WHO standards for water quality indicate that the minimum chlorine residual levels for stored drinking water should be approximately 0.20 mg/L. WHO guidelines also indicate that 0.50 mg/L of chlorine residual should be present for piped water distribution in order to maintain effective disinfection and avoid recontamination of water throughout the pipeline [17].

Additionally, the study utilized household survey data to provide information regarding accessibility of water sources. GPS points of households and water points were mapped to determine the accessibility of improved water sources by surveyed households.

A better understanding of water quality and contamination points in Bisate may provide clues about the sources of enteric disease transmission in the region. This information can be used to implement targeted interventions to improve water access and quality in Bisate, thereby decreasing the use of water sources in Volcanoes National Park, and improving the health of both the gorillas and humans in this area.

Background and Literature Review

Addressing the Global Burden of Diarrheal Disease

Diarrheal disease is the second leading cause of mortality in children under five years of age, causing more deaths in this population than malaria, measles, and AIDS combined [18]. WHO estimates that there are approximately 1.7 billion cases of diarrheal disease annually [1]. It is estimated that roughly 88 percent of these cases are caused by poor water, inadequate sanitation facilities, and improper hygiene [1].

Research suggests that interventions to improve water supply, water quality, sanitation, and hygiene are all effective in reducing diarrheal disease and associated mortality [19-21]. In a meta-analysis of 46 water, sanitation, and hygiene studies, Fewtrell, *et al.* found that hygiene, water supply, and water quality interventions had varying levels of efficacy in reducing the risk of diarrhea [19]. The study found a 37 percent mean reduction in the risk of diarrhea associated with hygiene interventions, a mean risk reduction of 25 percent associated with water supply interventions, and a mean risk reduction of 31 percent associated with interventions that addressed water quality [19]. Further interventions that combined multiple targeted improvements were found to reduce diarrheal risk by an average of 33 percent [19]. A more recent study by Clasen, *et al.* found that strategies to improve water quality alone were effective even without interventions to improve water supply or sanitation. Further, the study found that hygiene promotion may not be necessary for such water quality improvement interventions to be effective [22].

In 2000, the United Nations included water and sanitation as a target in its Millennium Development Goals. The target, 7.C, seeks to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" [2]. In order to track progress towards the goal, the WHO/UNICEF Joint Monitoring Programme for Water and Sanitation (JMP) set two indicators: "reasonable access to an improved water source" and " access to improved sanitation" [5]. In a rural area, "reasonable access" is defined as the ability to obtain at least 20 liters of water per person per day within one kilometer of the household [5]. An improved water source is one that is "more likely to provide safe water" as compared to an unimproved source. "Improved sources" include protected dug wells or springs, public standpipes, and rainwater collection systems [3]. However, not all "improved" water sources are necessarily safe for human consumption. Improved sources may still contain pathogens, especially if the water is not treated [23]. Contamination may also occur as a result of inadequate treatment and improper tap functioning [23]. Thus, the quality of drinking water from improved taps should also be considered when measuring progress towards greater water access.

In March 2012, the JMP announced that the target for safe drinking water had been met [3]. While the target was met globally, most countries on the continent of Africa did not reach the UN goal, and over 40 percent of the world's population without access to safe water lives in the countries of sub-Saharan Africa [3]. Moreover, the targets only measure "reasonable access", and do not consider water quality as previously discussed.

Determinants of Microbiological Water Quality

Microbiological water quality is dependent on numerous factors, which can influence changes in the quality of a single source of water over time and throughout various water testing locations [24, 25]. Water is often contaminated with environmental matter, including human and animal feces, soil, and detritus [24]. Particulates can be deposited into commonly used water sources through streams or rivers that pick up bacterial pathogens, or after rainfall events during which the pathogens are flushed into water sources from soil run-off that may contain animal and human feces [24].

Seasonality of water contamination has been investigated in numerous studies, and rainfall has been associated with increases in source water contamination [24, 26-28]. In rural Uganda, researchers found that that the predominant factor contributing to microbiological contamination of water sources was "local recharge" of water sources after rainfall. The study found that the most significant sources of feces were from dumps or drains, as opposed to sanitation facilities such as pit latrines [24]. Water has also been less contaminated overall during the dry season when compared to the rainy season [24, 25]. Levy, *et al.* found that while concentrations of contaminants were higher after rain events, consistent rainfall resulted in lower levels of *E. coli* [25]. The authors attributed this finding to a “runoff effect” in which fecal contamination is flushed out of the environment with consistent rainfall.

Although water contamination can vary seasonally, variation in contamination levels may be even greater on a shorter time scale. Temporality of water contamination was analyzed on multiple scales during a study of source water in rural Ecuador. Levy, *et al*. found that there was more overall variability in water quality on an hourly basis as opposed to a daily or weekly basis [25]. This occurred due to the fact that people were physically entering the water source, a river, during water collection. Contamination subsequently increased during times when many people were collecting water from the river [25].

Research has also implicated shallow or poorly maintained wells as vulnerable to contamination [24]. This has also been corroborated by studies that indicate that the use of improved water sources such as boreholes and protected dug wells result in decreased diarrheal illness, due to decreased water contamination [21, 22]. However, improper maintenance of even "improved" water sources can be detrimental to water quality.

Evaluating Microbiological Water Quality

Microbiological water quality is commonly assessed through the presence of indicator organisms, which are used as a surrogate for measurement of specific pathogens themselves. As pathogens can be difficult to detect in the environment and may only occur in low concentrations, proxy organisms can indicate the presence of potentially harmful contamination [29]. Ideal indicators should only be present when pathogens are present and should not naturally exist in the water source under consideration. They should not be able to multiply in the environment, and should respond to water treatment in the same manner as the pathogen. Further, the concentration of indicator organisms should be correlated with the concentration of the pathogen(s) for which they serve as surrogates, but the indicator concentrations should be higher than those of the pathogen [29].

Total coliforms and fecal coliforms are both commonly used as indicator organisms [14]. The total coliform group is defined as "all aerobic and facultative anaerobic, non spore-forming, Gram-negative rods that ferment lactose with gas formation within 48 hours at 35°C" [14]. Total coliforms are found throughout the environment, including in the soil and decaying leaves. Generally, total coliforms do not cause illness, but are typically used as an indicator of water treatment efficacy and overall water quality as they can signify presence of more harmful bacteria. Detection of total coliforms in drinking water is typically followed by additional testing for other contaminants [30].

Fecal indicators are used as a sign of human or animal fecal contamination, and may also signify the potential for other pathogens in the water. *Escherichia coli* has been used as a indicator of fecal contamination since the late 1800s and is generally the preferred indicator for this type of contamination [15]. *E. coli* exist in the intestinal tract of humans and other warm-blooded animals. As *E. coli* have a limited survival time outside the body and do not naturally reproduce in the environment, they are considered to be a reliable indicator of recent fecal contamination [15].

Water and Diarrheal Disease in Rwanda

Rwanda is the most densely populated country in the world, with over 12 million people inhabiting slightly over 26,000 square kilometers (United States Central Intelligence Agency, 2014). Known as the "land of a thousand hills", Rwanda's landlocked location and hilly terrain have caused difficulty for people in many areas, especially rural villages, to obtain an adequate quantity of water [6]. Additionally, many commonly used water sources are contaminated by fecal matter and other pollutants [7].

This may be a contributing factor to the high burden of diarrhea in the country. Diarrheal diseases are the second highest cause of morbidity and mortality in Rwanda; in 2012, diarrhea accounted for 18.1 percent of treatments across surveyed health centers in Rwanda [31]. This percentage does not include cases that were not reported to health centers or who did not seek treatment.

Rwanda suffered a widespread genocide in 1994 which significantly impacted the country's livelihood and infrastructure. The government of Rwanda estimated that shortly after the genocide, access to an improved water source dropped from 64 percent in 1990 to 39 percent [32]. In 2000, Rwandan President Paul Kagame established "Vision 2020", a comprehensive government program with the objective of transforming the country from a low-income to a middle-income country [33]. To reach this goal, the country developed several plans, including the National Policy and Strategy for Water and Sanitation Services and the Economic Development and Poverty Reduction Strategy. Priority action items for rural water supply in these plans include encouraging donors to pool funding for rural water, developing technical assistance for private water supply operators, and monitoring performance by water operators [32].

A large component of Rwanda's action plans for water relies on decentralization of water authority and public-private partnerships for water supply. One of Rwanda's most prominent water companies is EWSA, the Energy, Water, and Sanitation Authority, which was originally founded as "Regidiso", and later known as "Electrogaz" [34]. In 2013, EWSA had approximately 118,000 customers, predominantly in urban areas, across all of its operations, which include the provision of water and electricity [34]. Rural areas in Rwanda more commonly rely on other public-private partnerships, with nearly 30 percent of rural water operations managed by private operators [32]. Some of these operations are supported by grants from other countries; in 2007, the Japanese International Cooperation Agency funded a water supply project in three rural districts in Rwanda. The project served approximately 43,000 people and included support for community management and maintenance of hand pumps and wells [35].

Through the action plans and partnerships established in the last few years, the Rwandan government plans to significantly increase improved water and sanitation coverage. Various targets for water and sanitation were established in the government action plans. Vision 2020 seeks to increase water and sanitation coverage to 100 percent by 2020 [33]. The 2012 Economic Development and Poverty Reduction Strategy looks to increase coverage to 80 percent for water and 47 percent for sanitation by 2015 [32]. It is currently estimated that only 69 percent of the population of Rwanda has access to an improved water source of any type [5].

Disease Transmission between Gorillas and Humans

Changes in land use due to the growing human population have resulted in shifting dynamics between humans and animals. With increased human encroachment into animal habitats, there has been a subsequent increase in threats to both human and animal health [36]. Research has indicated that transmission of anthropozoonotic disease between humans and nonhuman primates is possible due to genetic similarities [36-39]. The most common transmission routes between the two populations are respiratory and fecal-oral, although researchers propose that contact with contaminated fomites, such as shoes and clothes, may also contribute to pathogen transmission [38]. Research has shown that monkeys are reservoirs for various human pathogens including the yellow fever virus, and *Mycobacterium tuberculosis* [39].

Human-animal pathogen transmission is difficult to monitor in instances where contact between the two populations is illegal, such as in national parks. While it may be illegal for human to enter these protected areas, they may do so in an undetected manner, which makes it difficult to enforce regulations. The potential for transmission is especially concerning where there is regular human-animal contact, such as eco-tourism trips where humans are led on tours to see groups of habituated animals in their native habitats. Though there are generally regulations that dictate the standard of health for visitors and the level of human-animal interaction that is permitted, tourists often pay a large sum of money for these trips. Therefore, they may forgo disclosure of symptoms of illness to ensure they can participate.

Recent outbreaks have demonstrated the ineffectiveness of regulations in minimizing the risk of human-animal pathogen transmission. In Volcanoes National Park, Rwanda, visitors are charged $750 USD to participate in the gorilla trek. All participants are required to maintain a distance of seven meters and are asked not to visit the gorillas if they have a cold, flu, or other respiratory illness [40]. However, between 1990 and 2010, 18 outbreaks of respiratory-illness occurred among the mountain gorilla populations that were habituated for ecotourism in Volcanoes National Park, with nearly all of the gorilla groups experiencing an outbreak [41]. Many of the gorillas recovered naturally; however, 35 of these endangered animals required treatment by veterinarians [41].

While it may be evident that a human or gorilla is suffering from respiratory illness due to symptoms like sneezing and nasal discharge, it may be more difficult to determine if someone is infected with an enteric parasite. However, parasites are common among gorillas, and there is evidence to suggest human-nonhuman primate transmission of enteric parasites. From 1995 to 1997, a study of 74 mountain gorillas was conducted in Volcanoes National Park, Rwanda [42]. Ninety-eight fecal samples, all of which were less than an hour old at the time of collection, were analyzed. Out of the 74 gorillas, 66 were infected with two or more parasites. Protozoa, including *Giardia* spp. were found in 63 of 70 fecal samples [42].

Researchers have noted that while a number of previous studies have been conducted in the same or nearby gorilla habitats, including a 1976 study that was published in Dian Fossey's Gorillas in the Mist, parasites that were previously unreported, such as *Trichuris* spp., *Chilomastix* spp., and *Endolimax nana*, were detected in later studies [42]. Further, the prevalence of infections, such as *Campylobacter* spp. and *Salmonella* spp., has increased in some human-habituated primate populations. In Bwindi and Mgahinga National Parks in Uganda, the prevalence of these infections doubled in a population of mountain gorillas from 1994 to 1999 [43]. Investigators speculate whether the observed rise in the prevalence of infections and types of parasites detected may be due to the fact that human activities, such as ecotourism and military monitoring, have increased in recent decades.

Genetic analyses also suggest similarities between parasite species found in the fecal samples of nonhuman primates and those that affect humans. One study found that gorillas whose habitats had a great amount of overlap with human and livestock habitats were affected with species of *Escherichia coli* that were genetically similar to those species found in the overlapping human and livestock populations [44]. The study observed that *E. coli* species found in gorilla populations that did not have as much human contact were not as genetically similar to those found in humans. In the Volcanoes National Park study conducted by Sleeman, et al, the *Trichuris* spp. eggs detected in the gorilla fecal samples were genetically indistinguishable from the human species of *Trichuris*, known as whipworm [42]. *Trichuris* sp. is known to cause severe enteric illness in both humans and nonhuman primates. Genetic similarities between the pathogens found in human and animal feces samples may indicate the potential for cross-species transmission of these pathogens.

Other studies conducted in Kibale National Park, Uganda, have demonstrated nonhuman primate infection with various gastrointestinal parasites that are also known to cause human morbidity and mortality. Species including *Ascaris* spp. and *Strongyloides* spp. have led to symptoms such as mucosal inflammation, intestinal obstruction, and diarrhea in humans as well as in populations of Red Colobus, Black and White Colobus, and Redtail guenon monkeys in Kibale [45, 46].

Further research is necessary to understand the mechanisms of disease transmission between humans and nonhuman primates. Current theories include the idea that habitat disturbance caused by an increase in human entry creates stress, which in turn lowers immunity and leads to increased susceptibility to pathogens among the nonhuman primates [39]. Another theory is that as the size of animal habitats are decreasing due to human encroachment, animals are being restricted to smaller areas that may or may not have higher concentrations of parasites in the environment and more frequent opportunities for transmission due to increased population density [39]. Regardless, the potential for disease transmission necessitates water and sanitation interventions that target both human and nonhuman primate populations.

The Dian Fossey Gorilla Fund International

The Dian Fossey Gorilla Fund International (DFGFI) has been working to protect the endangered mountain gorilla (*Gorilla beringei)* since 1967, when zoologist Dian Fossey established Karisoke Research Center [47]. When Karisoke was founded, Fossey feared that the world's mountain gorilla population faced extinction by the end of the 20th century. Shortly after Fossey's death in 1985, less than 300 of the gorillas existed in the wild, and they were threatened by poachers as well as environmental degradation [47]. Through extensive efforts by conservationists, the gorilla population has more than doubled to 800 animals today. It is estimated that around 500 of these animals live in the three national parks that house the Virunga Mountains, including Volcanoes National Park in Rwanda [12]. Today, Karisoke operates out of Musanze, Rwanda, and works primarily in Volcanoes National Park [11]. Gorilla trackers and researchers collect daily information on the gorillas, studying their behaviors and interactions, in addition to preserving biodiversity in their habitat. The organization has also worked with the government to institute educational and legal campaigns to decrease gorilla poaching [47].

In the last decade, DFGFI expanded its efforts to include human health, recognizing the interconnectedness between humans, primates, and their habitats. The DFGFI Ecosystem Health and Community Development Program began in 2004 with the goal of decreasing the prevalence of intestinal parasites in the Bisate Catchment Area of

Rwanda [47]. The program distributed de-worming medications to Bisate residents and constructed a centrally located water tank to improve access to water in the community. DFGFI also built a rainwater catchment system at its trackers' house. The ultimate objective of the program is not only to improve the health of the Bisate residents, but to decrease their need to go into the park for water or other purposes, further protecting the gorillas from human activities and potential disease transmission [11].

The Bisate Catchment Area

An interface between two environments, the Bisate Catchment Area serves as a region of unique ecological importance. The area is not only home to approximately 20,000 people, but also one of the few remaining habitats of the endangered mountain gorilla (Richardson, 2012). Despite the entry laws, the forest's natural resources, including water, continue to attract villagers inside the park's boundaries. Moreover, Volcanoes National Park has become one of the centers of Rwanda's growing tourism industry. Gorilla treks in the park started in 1955, and attempts to habituate the mountain gorilla population to humans began shortly thereafter [48]. Popularity of the treks increased quickly; however, genocide and related violence brought tourism to a halt between 1994 and 1998. As the country stabilized, the Rwandan government developed a strategy to increase tourism to its previous levels, including marketing campaigns and "high end eco-tourism" as opposed to mass tourism [48].

There are now seven habituated groups of mountain gorillas that tourists can visit. Gorilla treks in Volcanoes National Park attracted almost 20,000 visitors in 2008, generating around US $8 million [49] In recent years, tourism has become Rwanda's greatest source of foreign currency, earning about US $293.6 million in 2013 [50].

Eco-tourism in Volcanoes National Park has positive and negative implications for the area's ecology. Eco-tourism is undoubtedly beneficial to the growth of the country and has also been credited with increasing awareness and support for gorilla conservation. However, gorilla tourism has inherently increased the number of people from various places around the world that come into contact with the animals. Habituation has also led to an increasing number of gorillas observed leaving the park [11]. This increase in human-animal contact has heightened the risk of disease transmission, including infection by enteric pathogens, for both populations.

The Bisate Catchment Area has both limited water supply and quality. While the park has natural sources of water located inside its boundaries, its distinction as a protected ecosystem has led to stringent regulations requiring all persons entering the park to have a permit. Further, despite receiving about 1,200 mm of rainfall per year, rain has not been a reliable source of water [8]. The weather in Bisate is characterized by two rainy seasons, one longer season occurring from February through early June, and a second shorter season from early September to December [9]. However, the area has porous volcanic soil, which absorbs most of the rainwater [8]. As a result, residents of the Bisate Region must rely on various man-made water taps that have been built throughout the community.

The Bisate Catchment area is served primarily by three natural water sources that are located inside Volcanoes National Park: Bunyenyeri, Bushokoro, and Myase. Two of these sources, Bunyenyeri and Bushokoro, provide the water for community taps through a series of pipelines. The community taps served by these two sources are free to the public. During the dry season, however, many of these wells have decreased water supply, further limiting access to water by the residents [9]. The community also has a number of treated water taps that charge a set price for each jerry can that is filled. These taps dispense water that is sourced and chlorinated outside Bisate [10].

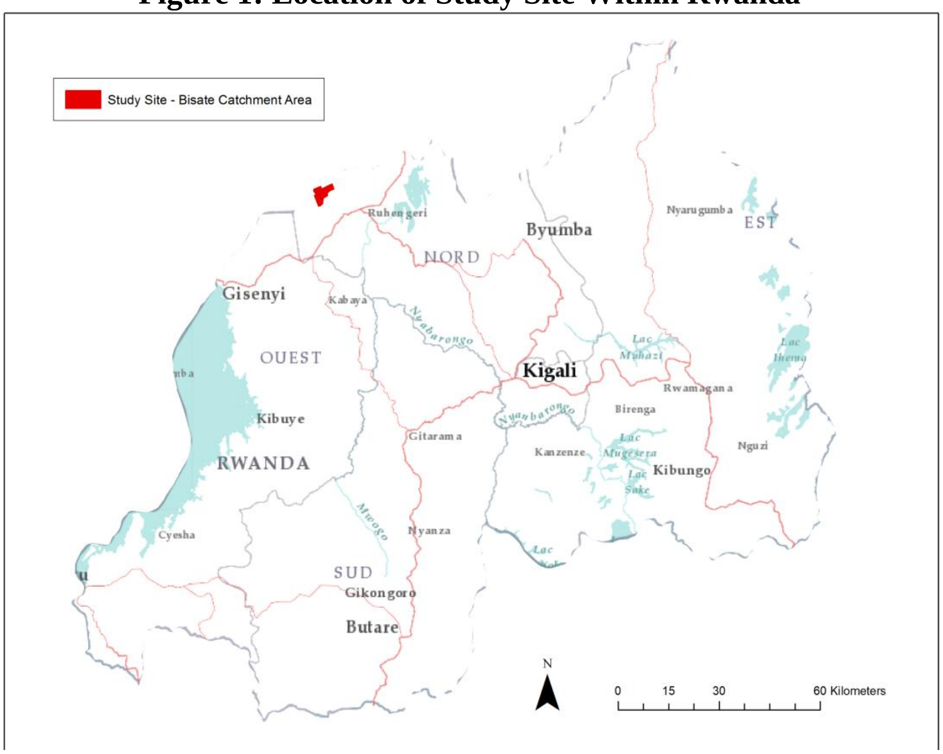
A study conducted in 2007 found that the Bushokoro Well in the park and the connected community taps, as well as taps connected to the Bunyenyeri Spring, contained total coliforms. The Bunyenyeri Spring itself was not tested. None of the water points tested in the 2007 study were found to have *E. coli* contamination [8]. However, water samples were only taken once at each site. Since *E. coli* indicates recent fecal contamination, it is possible that no animal or human had recently been in the vicinity of the well at the time the samples were collected.

While estimates of diarrheal disease in Bisate are difficult to determine, clinic records show that over 53 percent of people tested in 2011 (n=996) had some type of intestinal parasite infection, predominantly helminth infections that are associated with poor sanitation and hygiene [51]. This statistic represented a decrease from 2003, when over 90 percent of those tested were infected with intestinal parasites [51]. These results suggest that there has been significant progress in decreasing infection with some intestinal pathogens in Bisate, though it is unclear if the reduction was a result of specific interventions to improve water supply or a result of deworming campaigns that have been conducted in the region. Regardless, the prevalence of diarrheal disease in Bisate, particularly due to intestinal parasites, remains high. This disease burden underscores a need for continued improvement of water, sanitation, and hygiene and diligent monitoring of water quality for microbial contamination.

Methodology

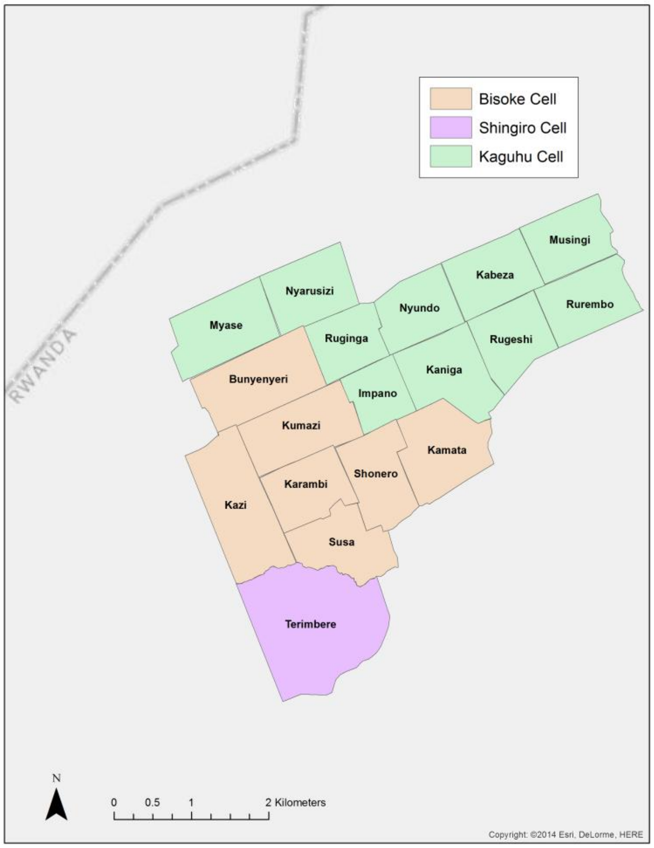
This study was part of a larger project developed by the Center for Global Safe Water at Emory University in collaboration with the Dian Fossey Gorilla Fund International (DFGFI) and funded by the Emory University Global Health Institute (GHI). A multidisciplinary team of six Emory University researchers conducted a baseline assessment of livelihoods, healthcare utilization, and water and sanitation. All research was conducted in the Bisate Catchment Area of Rwanda from May to July 2013. The study site was determined by DFGFI due to its proximity to Volcanoes National Park, where DFGFI conducts much of its research (Figures 1 and 2). This study was determined to be exempt from review by the Emory University Institutional Review Board (IRB). This study was approved by the National Ethics Committee of Rwanda, after a presentation to members of the committee (Appendices A and B).

Figure 1: Location of Study Site Within Rwanda



(Basemap obtained from ArcMap® database)

Figure 2: Location of Villages Comprising Study Site



(Basemap obtained from ArcMap® database)

Household Survey

Five enumerators administered household surveys in Kinyarwanda, the local language. Training for the enumerators was conducted over five days in June 2013 and included instruction on informed consent, general survey administration, and a pilot test of the survey in one village, the results from which were not included in the final data pool.

The household survey was conducted in the 18 villages that comprise the Bisate Catchment Area, which include Bisoke and Kaguhu cells[1] and the village of Terimbere, located in Shingiro cell. Consent was obtained from all village leaders prior to research.

[1] The term cell refers to an administrative district comprised of several villages

The survey team included the five enumerators and at least two Emory University students. The team visited one village per day and administered 20 surveys in each village.

Households were selected using stratified random sampling. A map generated from Google Earth was analyzed to enumerate the number and distribution of households in each village. The number of households divided by the intended number of surveys (20) for each village was used to define the sampling interval (*n*). These maps were also cross-referenced for accuracy with additional maps of the Bisate Catchment Area, which were provided to the Emory/GHI student team by village leaders. Upon arriving at the village, every *n*th household was flagged to be surveyed. If no one was present in the household, it was noted, and the next nearest house was chosen for the survey.

During a weekly review of survey results, it was found that a region of one village was left out of the original sampling frame. To correct for this error, a proportional sample of five additional houses was surveyed in the region, and weights for each village were adjusted accordingly. Thus, a total of 365 houses were surveyed.

Survey data were cleaned and entered into a database created using Epi-Info® and cross-checked for accuracy to ensure that less than five percent of the data had discrepancies. Any discrepancies were corrected upon review. The data were weighted according to village size and analyzed using SAS Enterprise® software. Frequencies were generated for each specified variable, and tables were created using Microsoft Word®.

Mapping

A Global Positioning System (GPS) point was recorded at each surveyed household using a handheld device. The numbers were listed on corresponding household surveys and recorded on an Excel spreadsheet. Spatial analysis was conducted through analysis of the GPS points using ArcMap® software. To create the maps that depict distance from closest water source, buffers were applied to the maps, and all households outside one kilometer were highlighted. Topographic base maps were sourced from the ArcMap® database.

Water Quality Testing

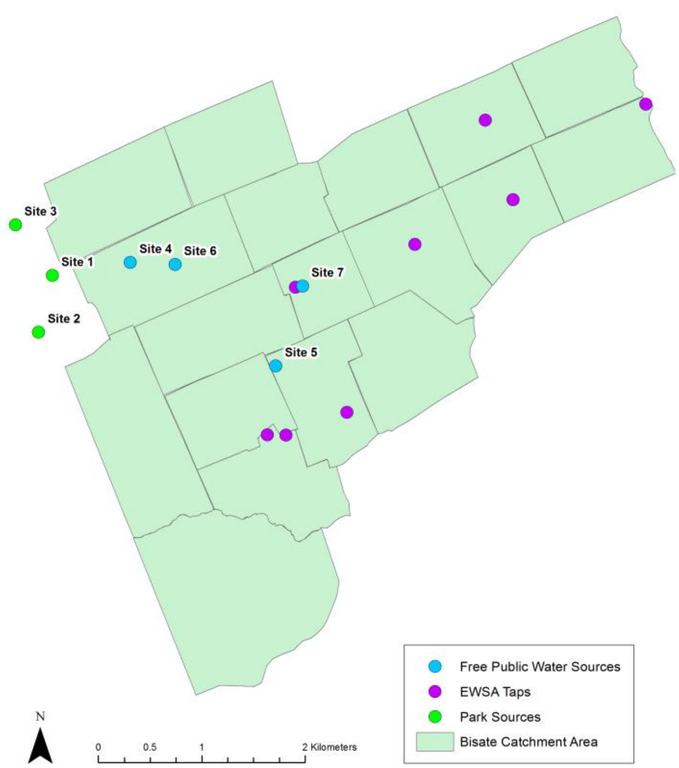
Microbiological assessment of water quality was conducted using the IDEXX Colilert System® and Quanti-Tray Testing system® for detection of coliforms. Total coliforms and *E. coli* were used as proxy indicators for the presence of fecal contamination. Samples of approximately 100 milliliters (ml) were collected on a weekly basis from eight sources in the Bisate Catchment Area. The sources included five community taps and three sources located inside Volcanoes National Park (VNP); a spring, an unprotected well, and a stream. Descriptions of these sources are detailed in Table 1. Locations of the sources are detailed in Figure 3.

Table 1: Description of Sampled Sources in the Bisate Catchment Area, Rwanda

SITE #	SOURCE NAME	DESCRIPTION
1	Bunyenyeri Spring	Groundwater-fed spring located inside park
2	Bushokoro Well	Open well located inside park; collects water from streams running through the forest.
3	Myase Stream	Stream source located inside park
4	Bunyenyeri Tap (In potato field)	Tap located in a potato field; received water from the Bunyenyeri spring.
5	Bunyenyeri Tap (On main road)	Tap located on the main road connecting several villages; Received water from the Bunyenyeri spring.
6	Bushokoro Tap (Along path from Bisate to park)	Tap for tanks built by DFGFI. Water was sourced from Bushokoro in park and supplied to tap through a 1" PVC pipe
7	Bushokoro Tap (Near Bisate school and health center)	Tap located next to the schoolhouse in Bisate town center. Water was sourced from Bushokoro and supplied through a 1" PVC pipe that runs from the main source inside the park
8	Karisoke Trackers' House Tap*	Private tap supplied by water from a rainwater catchment system located at the Karisoke Research Center gorilla trackers' house.
--	EWSA Taps	Eight standpipes located in Bisate (seven were sampled). Taps are managed by EWSA. Water was sourced and chlorinated at an unknown location before being piped to various taps through 5" steel pipes

*Site 8 not mapped as it is a privately owned tap

Figure 3: Locations of Selected Water Sources, Bisate Catchment Area, Rwanda



All water sources were chosen for sampling as a result of the previous work of the DFGFI Ecosystem Health and Community Development Program Director, who indicated that the sources were those most commonly used by the residents of Bisate [9]. Upon sampling each source, environmental characteristics of the sample site were recorded, namely the location, type of source (tap, well, spring, etc), and any recent notable weather occurrences, such as rainfall. A GPS point was also taken at each site.

Two samples were collected from each source per week for seven weeks. However, park sources were not sampled during the first week and one community source could not be sampled during the last week. Water samples were collected in Whirl-Pak bags, immediately sealed, and placed on ice. The samples, along with a field control of sterile water from the Ruhengeri Hospital, were returned to the laboratory at the hospital between 3-5 hours after collection and processed the same day. Samples were diluted with sterile water using a ratio of 1:10, and initially 1:100, though this second dilution was determined to be unnecessary after the first two weeks of testing. An undiluted sample was also tested each week. Colilert® reagent containing β-galactosidase β-glucuronidase was then added to each sample and shaken until thoroughly dissolved [52]. Each sample was then poured into the Quanti-Tray® and closed using the Quanti-Tray® sealer. The sealed sample trays were incubated at approximately 37.5°C for 22 to 24 hours.

After incubation, water samples were analyzed using the most probable number method (MPN). The MPN method uses the enumeration of viable organisms in several replicate tests to estimate an original, undiluted concentration of the organisms, with a confidence level of 95 percent [53, 54]. Wells that were positive for total coliform bacteria turned yellow after incubation, and those that were positive for *E. coli* fluoresced under ultraviolet light. Positive wells were enumerated and converted to the most probable number of bacteria per 100 ml using the Quanti-Tray® MPN table. Analysis of the microbiological data was conducted using Microsoft Excel®. Results were recorded on paper by two members of the research team and cross-checked for accuracy before entering into a Microsoft Excel® spreadsheet. The concentrations of total coliforms and *E. coli* were estimated from two dilutions per sample by taking the average of the two concentrations in 100 ml of water. The Quanti-Tray® system generally has a limit of detection ranging from <1 to 2,049 indicator organisms in 100 ml of water [52].

Two additional water sources were also included in the initial sampling pool, but had evidence of chlorine residual. These sources were later found to be managed by the Rwanda Energy, Water, and Sanitation Authority (EWSA), which supplies water through taps that were constructed by an unidentified Chinese company. Six other water sources (eight sources in total) in the Bisate Catchment Area were identified as part of this project and will be referred to throughout this paper as the "EWSA taps". As one of the EWSA taps was locked and not in service, samples from seven of the eight sources were tested for free residual chlorine. Microbiological testing of chlorinated sources with the Colilert® Detection System requires the use of Whirl-Pak bags containing sodium pentathiol. Since these Whirl-Pak bags were not available to the research team, the samples from the EWSA taps were not subjected to further microbiological testing.

Results

Water Quality Testing

A total of 38 samples were tested throughout the study period to determine the concentration of *E. coli* and total coliforms in commonly used water sources in the Bisate Catchment Area. The average concentrations of *E. coli* and total coliforms were analyzed for water samples from each source (Tables 2 and 3). Total coliforms were consistently detected in water samples from seven of the eight water points tested. Varying levels of *E. coli* were present in samples from all sources except those connected to the Bunyenyeri spring.

Table 2: Total coliform concentration in water samples taken from selected sources in the Bisate Catchment Area, May – July 2013

Concentration of Total Coliforms (MPN/100 ml)*†								
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
28-May	-	-	-	1.0	1824.0	89.0	1266.5	1311.9
4-Jun	ND	398.4	161.7	2.0	499.6	200.8	478.1	225.9
12-Jun	ND	106.7	145.2	2.0	167.0	78.1	24,196.0	129.3
18-Jun	ND	121.6	350.7	6.2	321.8	268.3	76.5	211.6
26-Jun	ND	270.8	147.0	7.4	189.3	923.5	701.7	399.7
2-Jul	ND	102.2	36.6	10.5	111.3	39.9	577.1	891.1
9-Jul	ND	75.4	261.7	3.1	71.2	49.7	-	525.2

The dash (-) represents "no data"; the specified sources were not tested on these dates
ND = Non-detectable, below the limit of detection (< 1 MPN/100 ml)
*Each concentration was estimated from the average of two dilutions of each sample
† MPN refers to the most probable method of estimating concentration

Table 3: *E. coli* concentration in water samples taken from selected sources in the Bisate Catchment Area, May – July 2013

Concentration of *E. coli* (MPN/100 ml)*†								
Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
28-May	-	-	-	ND	ND	25.2	122.4	ND
4-Jun	ND	17.2	3.1	ND	ND	38.3	44.7	ND
12-Jun	ND	9.3	26.9	ND	ND	6.3	307.0	ND
18-Jun	ND	33.5	19.5	ND	ND	12.1	16.8	1
26-Jun	ND	48.7	5.2	ND	ND	362.4	216.0	1
2-Jul	ND	9.5	4.1	ND	ND	2.0	15.5	ND
9-Jul	ND	4.1	19.5	ND	ND	1.0	-	ND

The dash (-) represents “no data”; the specified sources were not tested on these dates
ND = Non-detectable, below the limit of detection (< 1 MPN/100 ml)
*Each concentration was estimated from the average of two dilutions of each sample
† MPN refers to the most probable method of estimating concentration

Bunyenyeri Spring and Connected Taps

Of all water sources tested, only samples from Site 1, the Bunyenyeri Spring had no detectable total coliforms in 100 ml of sampled water. This main source for the Bunyenyeri taps was a groundwater-fed spring with a covering over the source (Figures 4 and 5).

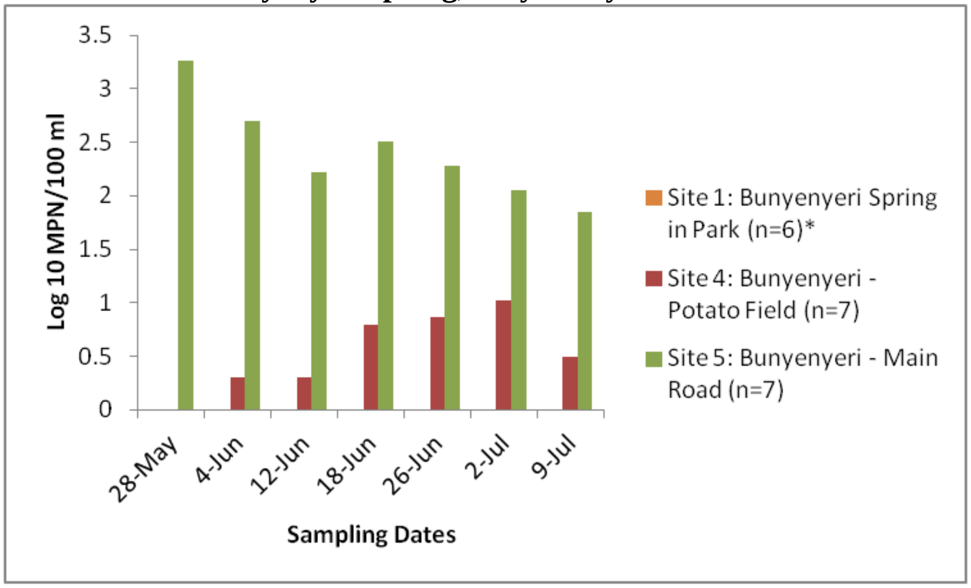
Figure 4: Bunyenyeri Spring (open), Volcanoes National Park, Rwanda

Figure 5: Bunyenyeri Spring (closed), Volcanoes National Park, Rwanda

Water from the spring in the park was directed to two taps in the community (Sites 4 and 5) through a buried pipeline which was not generally exposed above ground. Site 4 was a large well located in a potato field with a running tap. The tap did not have a valve, and therefore was observed to be consistently running throughout the study period. Site 5 was located on a main road which runs through the Bisate Catchment Area, connecting a number of villages. The tap for Site 5 also did not have a valve and was consistently running. However, the tap at this site was observed to have a very low water flow, essentially a slow drip, throughout the study period. A funnel fashioned out of a leaf was attached to the tap to facilitate water collection.

Water samples from both Bunyenyeri sites in the village had detectable levels of total coliforms (Figure 6). The concentration of total coliforms in water samples collected from Site 5 ranged from 71.2 to 1824.0 MPN/100 ml and was generally higher than in samples collected from Site 4, which ranged from 1.0 to 10.5 MPN/100 ml. *E. coli* was never detected in any of the Bunyenyeri water points, including the source inside Volcanoes National Park.

Figure 6: Total coliform concentrations (MPN/100 ml) in water samples from three sites connected to the Bunyenyeri spring, May - July 2013



*Total coliforms were never detected in Site 1

Bushokoro Well and Connected Taps

The Bushokoro Well (Site 2) was situated at the edge of Volcanoes National Park. It was an open well that collects water from streams that run throughout the forest (Figure 7). Analysis of the Bushokoro Well in the park and connected taps in the village revealed consistent detection of total coliforms and *E. coli*. Levels of total coliform in the park source ranged from 75.4 MPN/100 ml to 398.4 MPN/100 ml (Figure 10). The concentration of *E. coli* in the park source ranged from 4.1 to 48.7 MPN/100 ml (Figure 11). Water from samples taken at the Bushokoro water points had collectively the greatest frequency and magnitude of coliform and *E. coli* detection of all of the water sources tested.

Figure 7: Water running into Bushokoro Well, Volcanoes National Park

Water from the main Bushokoro Well was delivered to the village through a one-inch PVC pipe built by DFGFI as a part of their Ecosystem Health and Community Development Program, which runs from the park source to the community sources [9]. The pipe was exposed and visible at many locations throughout Bisate, and was also broken in many spots (Figure 8). During the first week of water testing, community members witnessed the research team photographing one of the breaks in the pipe. The following week, this break was covered in plastic wrap, and the week after, was covered with a rock (Figure 9). During a sampling trip conducted towards the end of the study period, it was noted that a jerry can had been placed upside down over one of the pipe breaks in order to collect water.

Figure 8: Broken PVC pipe connecting the Bushokoro Well in Volcanoes National Park to community taps in Bisate

Figure 9: Plastic covering wrapped around the Bushokoro Pipeline, Bisate, Rwanda

The Bushokoro pipeline connected the source in the park to two taps in the community. The first tap along the Bushokoro pipeline from the forest to the community was near two water collection tanks constructed by DFGFI (Site 6). The tanks are connected to a single tap, which was broken during the study period. Anecdotal reports indicated that the breakage had occurred as a result of arguments over water collection. Since the tap had been broken, water was collected through the outlet, which, when observed, was consistently running. The main Bushokoro Well also supplied water to a community tap in the center of Bisate (Site 7), which was located next to the Bisate Primary School and Bisate Health Center. The tap did not have a valve and water was always observed to be running from the tap. A leaf funnel was also created for water collection from this tap. Located about 100 feet away from the tap was a collection tank with an outlet for this tap.

Water samples from sites connected to the Bushokoro Well in the park yielded fluctuating concentrations of total coliforms and *E. coli*. However, there was no clear pattern of temporal variation in these concentrations. There was a wide range in the concentration of total coliforms found in samples from the two community taps together, from a low of 39.9 MPN/100 ml to a high of 24196.0 MPN/100 ml, the highest concentration detectable with the method of testing used (Figure 10). The *E. coli* concentration in samples from the well constructed by DFGFI (Site 6) ranged from 1.0 to 362.4 MPN/100 ml and the concentration in samples from the tap in the town center (Site 7) ranged from 15.5 to 307.0 MPN/100 ml (Figure 11). One notable occurrence was on the June 26 testing date, when there was a spike in *E. coli* contamination in both of the village taps. This testing date occurred after a heavy rainfall event, the only one observed during the study period.

Figure 10: Total coliform concentrations (MPN/100 ml) in water samples from three sites connected to the Bushokoro Well, May - July 2013

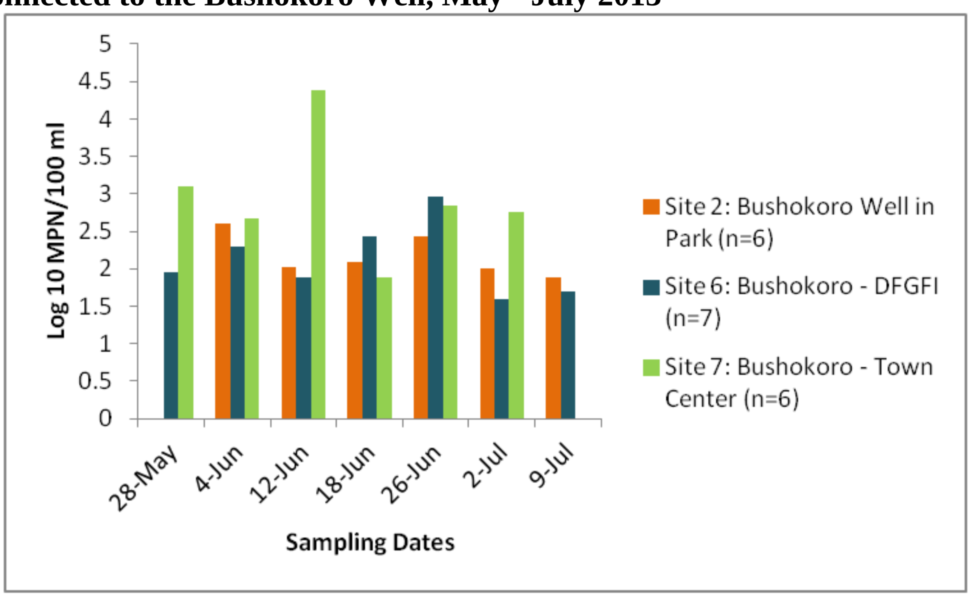
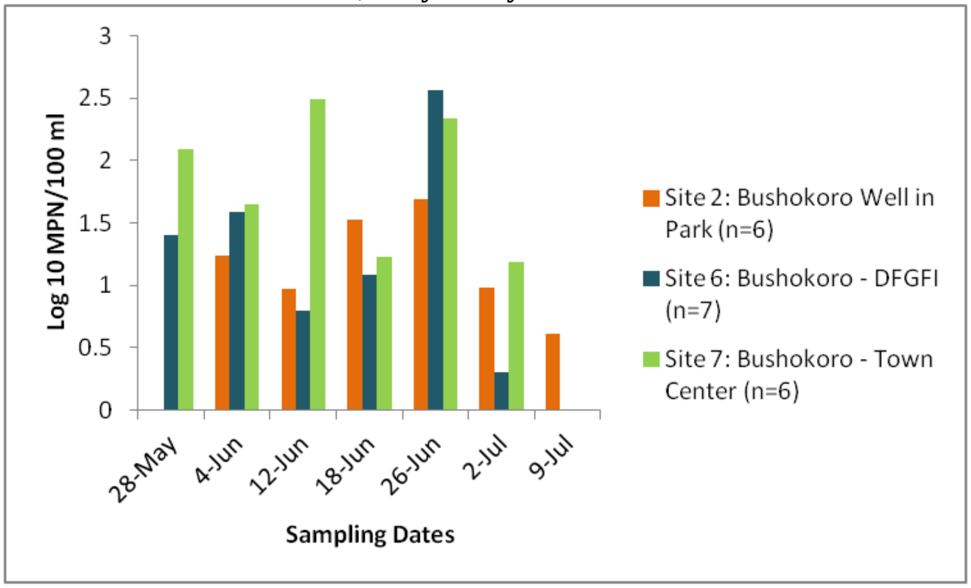


Figure 11: *E. coli* concentrations (MPN/100 ml) in water samples from three sites connected to the Bushokoro Well, May - July 2013



During the June 18 sample collection, it was observed that the tap at Site 7 was broken in the morning, but was fixed by the afternoon. During the week prior to the break, both total coliform and *E. coli* levels were at the highest measured to date. The samples collected on June 18 were collected in the afternoon, several hours after the usual sample collection time. The samples collected on June 18 had total coliform and *E. coli* concentrations that were among the lowest detected at Site 7. During the morning of June 18, several individuals were seen collecting water from an outlet about 100 feet away from Site 7, also sourced from Bushokoro. This outlet was sampled on the morning of June 18 and also showed evidence of *E. coli* contamination. However, the outlet was not open on any other sampling days and was therefore not included in further analysis.

Other sources

The Myase source (Site 3) was a stream located inside Volcanoes National Park (Figure 12). There was no evidence that this source supplied water to any community taps.

Figure 12: Myase Source, Volcanoes National Park

Samples from the Myase Stream in Volcanoes National Park (Site 3) contained varying levels of total coliform and *E. coli*, with no evidence of a consistent temporal trend. Total coliform concentrations ranged from 36.6 to 350.7 MPN/100 ml (Figure 13). *E. coli* contamination ranged from 3.1 to 26.9 MPN/100 ml (Figure 14).

Site 8 was located at a house owned by DFGFI, which is occupied by the Karisoke Research Center's Mountain Gorilla trackers. The house was supplied with water collected from an onsite rainwater catchment system. Water was diverted from the metal roof of the trackers' house and collected in a large plastic container. The faucet for the catchment system had a valve and was only turned on when water collection was necessary.

Samples from the rainwater catchment system at the Karisoke Research Center Trackers' House (Site 8) yielded total coliforms (Figure 13). The samples from this site were generally free of *E. coli*, except on June 18 and June 26, when a low level of *E. coli* (1.0 MPN/100 ml) was detected in these samples (Figure 14).

Figure 13: Total Coliform concentrations (MPN/100 ml) in water samples from the Myase Stream and Karisoke Trackers' House, May - July 2013

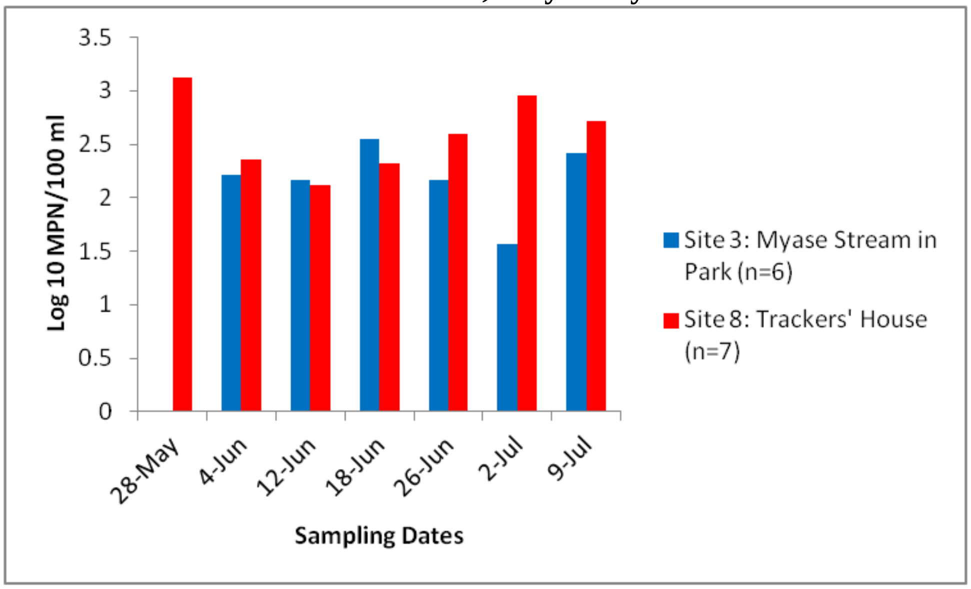
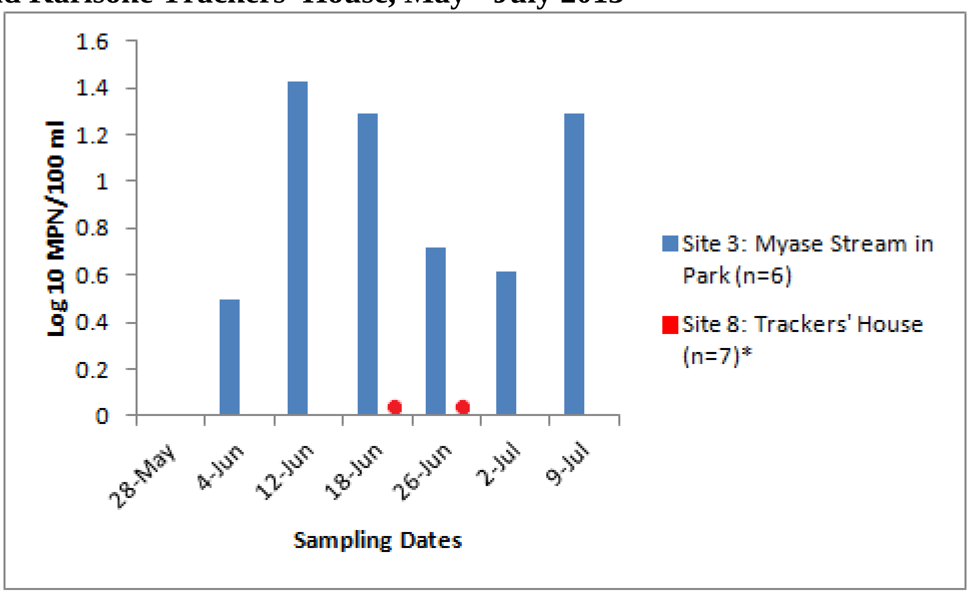


Figure 14: *E. coli* concentrations (MPN/100 ml) in water samples from the Myase Stream and Karisoke Trackers' House, May - July 2013



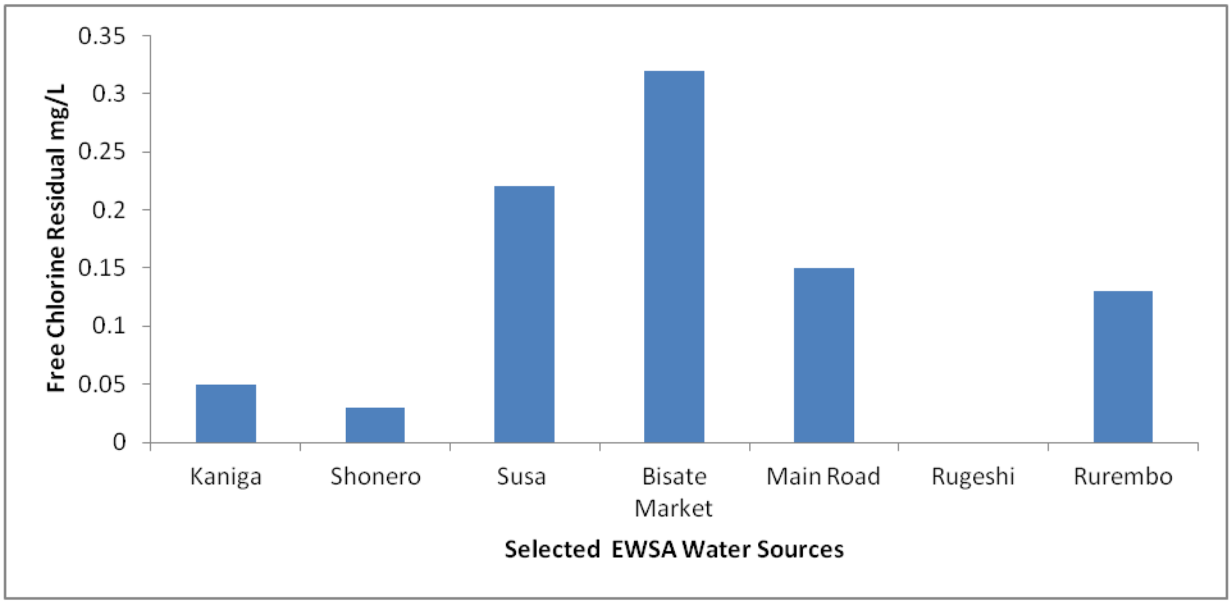
*The red dots on the 18th and 26th of July denote that a non-zero level of E. coli was detected on these dates.

EWSA Taps

The EWSA taps refer to a number of water taps located throughout the Bisate Catchment Area. These taps were built by Rwanda Energy, Water, and Sanitation Authority, in conjunction with an unnamed Chinese company. The water is sourced from and chlorinated at unknown locations outside of Bisate before being transported to the various community taps through steel pipes approximately 5 inches in diameter [10]. Each of the taps is owned privately; to utilize the source one must ask the owner to unlock the device with a key. The price of water is standardized at 15 francs per 20 liter jerry can [10].

Water samples from EWSA taps were excluded from microbiological analysis due to the presence of residual chlorine. Almost all the samples from EWSA taps were found to have positive free chlorine residual levels. Free residual chlorine levels ranged from 0.0 mg/L to 0.32 mg/L, with a mean of 0.13 mg/L (Figure 15). Only one source, located in Rugeshi, did not have a chlorine residual. Only two sources, those located in Susa and in the Bisate Market, met the World Health Organization minimum chlorine residual standard of 0.20 mg/L for stored drinking water. None of the sources met the WHO standard of 0.50 mg/L for piped water distribution [16].

Figure 15: Free residual chlorine levels in samples from seven selected EWSA taps in the Bisate Catchment Area



Self-reported Water Treatment Practices

Household survey respondents answered questions about water treatment practices. Of those respondents, 66.9 percent reported that they had treated their water in the past month. Boiling was the most common method of water treatment, used by about 99 percent of respondents who treated their water (Table 4). Among the 32.9 percent of households who reported that they had not treated their water in the past month, the most common reason for lack of treatment was that it was unnecessary, indicated by a little more than 14 percent of respondents (Table 5). Over 20 percent of respondents also provided their own answer to this question, however, these answers were generally similar to the answer that treatment was unnecessary, indicating that that the "water is already treated" or "water is already clean".

Table 4: Self-reported water treatment methods among survey respondents who indicated water treatment

Method of water treatment	Number of households n=248* (%)	95% Confidence Interval
Boiling	245 (98.8)	96.4 – 99.7
Filtering	9 (2.5)	1.2 – 6.4
Treatment product (tablets, liquid, or powder)	28 (7.0)	6.7 – 14.2

*A total of 365 respondents were surveyed; 248 of these respondents indicated that they treat their water

Table 5: Self-reported water treatment methods among survey respondents who indicated no water treatment

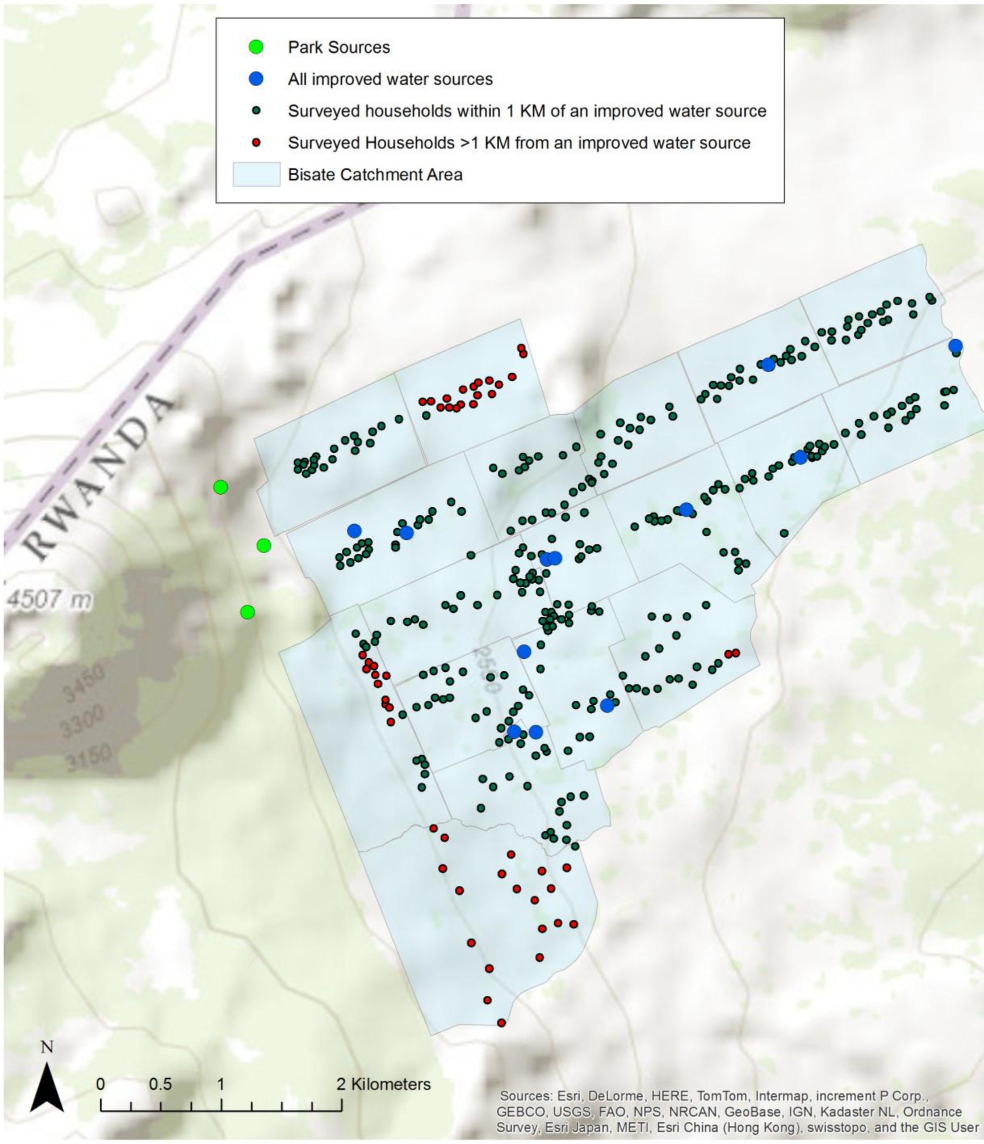
Reasons for not treating water	Number of households n = 113 (%)	95% Confidence Interval
Treatment products are unnecessary	51 (14.4)	10.6 – 18.2
Could not obtain wood to boil water	9 (2.2)	0.7 – 3.7
Do not like the taste of treated water	2 (0.7)	0.0 – 1.7
Ran out of water treatment products	2 (0.6)	0.0 – 1.5
Other	68 (20.3)	15.9 – 24.6
Don’t know	1 (0.3)	0.0 – 0.8

*A total of 365 respondents were surveyed; 113 of these respondents indicated that they did not treat their water

Water Source Accessibility

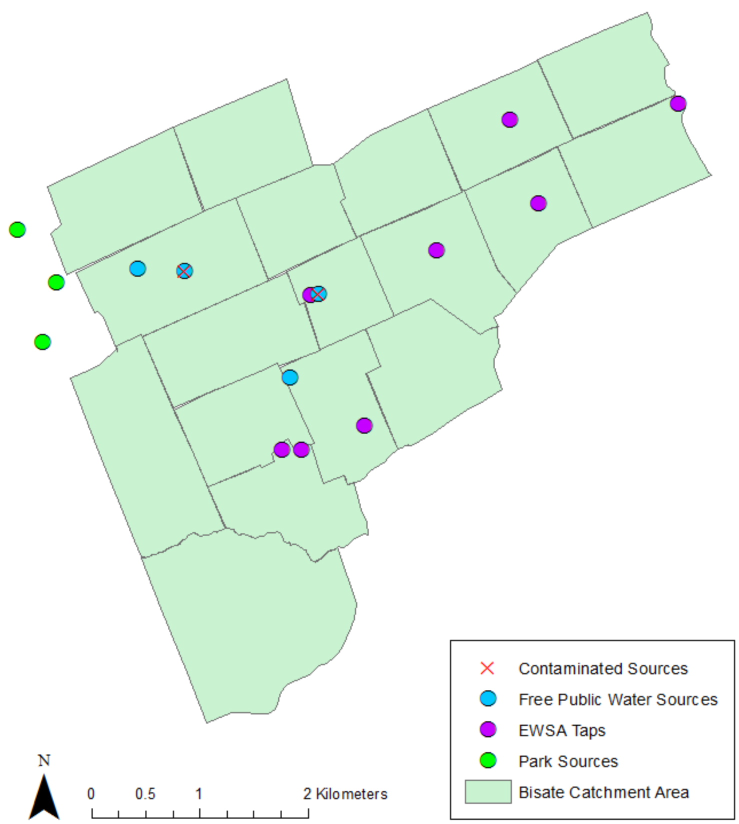
To determine the level of access to improved water sources, surveyed households were plotted on a map along with the locations of selected water sources (Figure 14). Households that were outside World Health Organization definition of "reasonable access to an improved water source", or one kilometer, were highlighted in red. Based on this calculation, it was found that 308 out of 365, (84.4%) of households surveyed were within one kilometer of an improved water source. However, it is important to note the topography of the region (Figure 16). The altitude in the Bisate Catchment was found to vary within the region, but generally increased with proximity to the park, ranging from roughly 2000 to 3000 meters. Therefore, people in households that are within "reasonable access" may actually be traveling one kilometer uphill to access their nearest water source, which requires a greater expenditure of kilocalories than traveling one kilometer on flat terrain.

Figure 16: Proximity of surveyed households to an improved water source in the Bisate Catchment Area



Microbiological water quality data was used to inform mapping of water source accessibility (Figure 17). Public water sources that were sampled were mapped according to their characteristics (EWSA tap, Park Source, or Public Tap) and sources containing *E. coli* (as per water quality testing results) were denoted as contaminated. When analyzed in conjunction with Figure 16, it is evident that despite the fact that 84% of surveyed households were within one kilometer of some type of improved water source, not all of these households are close to a water source that meets WHO standards for microbiological water quality and/or is free of charge.

Figure 17: Characterization of Selected Water Sources in the Bisate Catchment Area



The limited number of free water sources may lead to crowding of the sources, especially during the dry season. Household survey respondents were questioned about the length of their typical wait time at their most commonly used water source, both in the rainy season and in the dry season. Overall, more respondents had short wait times during the rainy season, in comparison to wait times during the dry season (Table 6). About 90 percent of respondents reported wait times of less than 10 minutes during the rainy season. In comparison, 58 percent of respondents reported wait times of greater than 10 minutes during the dry season, and approximately one-third of respondents reported waiting 30 minutes or more to collect water during the dry season.

Table 6: Seasonal variation in self-reported wait times among surveyed respondents for water from community taps in the Bisate Catchment Area, Rwanda

	Rainy Season		Dry Season	
Length of wait time (minutes)	Number of households n=357* (%)	95% Confidence Interval	Number of households n=359* (%)	95% Confidence Interval
< 10	322 (90.0)	86.9 – 93.0	151 (41.8)	36.9 – 46.8
10 - < 30	19 (5.5)	3.08 – 7.9	90 (25.4)	20.7 – 30.1
30 - 60	8 (2.4)	0.7 – 4.0	65 (17.7)	13.8 – 21.5
> 60	1 (0.3)	0.0 – 1.0	49 (14.0)	10.6 – 17.4
Don’t know	7 (1.9)	0.4 – 3.3	4 (1.1)	0.0 – 2.3

*data missing; total of 365 respondents were surveyed

Discussion

Water Quality

This study analyzed the water quality of community sources throughout the Bisate Catchment Area in order to determine the presence and magnitude of *E. coli* and total coliform indicator bacteria and the possible origins of water contamination, including temporal and spatial factors contributing to contamination. WHO guidelines for bacteriological water quality recommend that a 100 milliliter sample of water intended for drinking should not contain any detectable *E. coli* [17]. Of the three main water sources inside Volcanoes National Park, only one was found to be consistently free of *E. coli*. All water points connected to this uncontaminated source were also free of *E. coli*, while the other sources and connected water points revealed varying levels of *E. coli* contamination ranging from 1.0 to 362.4 MPN/100 ml. This study was consistent with the results of a previous study by Howard, *et al*. that was conducted in Uganda, a country located just north of Rwanda. The study was conducted over 13 months and sampled 25 protected springs on a monthly basis. Similar to the results of our study, Howard, *et al*. reported wide temporal and spatial variations in the concentration of fecal streptococci and thermotolerant coliforms (99 percent of which were *E. coli*) in shallow groundwater, ranging from 1 to 23,000 cfu/100 ml[2] [24].

We observed measurable differences in water quality amongst the main sources located in Volcanoes National Park. In contrast to Bushokoro Well and Myase Stream, the Bunyenyeri Spring was free of *E. coli* contamination at its starting point in the park. Because the covering to the spring can be open or closed as necessary, this was not an entirely surprising finding, since it is unlikely that the covering is open unless people are fetching water. Neither the Bushokoro Well nor the Myase Stream have a cover, and therefore are more susceptible to activities that occur in the surrounding environment. Furthermore, both of these sources are fed from surface water that runs through the forest and can pick up contamination through run-off.

The study was somewhat consistent with previous findings regarding water quality in the Bisate Catchment Area, especially regarding contamination of the Bushokoro source with *E. coli*. Research conducted in 2007 reported that the Bushokoro Well in the park and connected taps, and taps connected to the Bunyenyeri Spring contained total coliforms. Total coliform concentrations measured in this study also varied greatly, ranging from less than 100 cfu/100 ml to 2200 cfu/100 ml [8]. The

[2] cfu refers to colony-forming units, an estimate of viable bacteria in a sample

Bunyenyeri Spring itself was not tested in the 2007 study. Our findings supported this conclusion for these water points as well, as we found a wide range of variation in samples from these sources.

However, there were several differences between this study and the earlier study conducted in Bisate. This study also included the Bunyenyeri Spring, which was not found to contain total coliforms. Further, none of the water points tested in the 2007 study were found to have *E. coli* contamination [8]. In comparison, this study found *E. coli* contamination throughout all of the points connected to the Bushokoro source. It is important to note that in the previous study, water samples were only collected once at each site, as opposed to this study, which conducted sampled once per site for seven weeks. Since *E. coli* indicates recent fecal contamination, it could be that no animal or human had recently been in the vicinity at the time of the water samples were collected. We detected *E. coli* in this water source throughout the seven-week study period, which suggests that there was regular human or animal activity in the area. The 2007 study used the membrane filtration method; the Colilert system used in this study has been demonstrated to have somewhat greater sensitivity for the detection of total coliforms and *E. coli*, in comparison to the membrane filtration method [55]. Finally, this study tested two dilutions on each sampling date, while the other study only tested one dilution.

Further research is required to determine the causes of contamination of the Bushokoro source; however, there are several possible explanations. The Bushokoro area is commonly used as a starting point for tour groups beginning their trek to see the mountain gorillas. Since it is so close to the park boundary, it is commonly guarded by forest rangers. It is unknown how long this area has been used for this purpose; however, it would be interesting to determine whether tour groups frequented the area, or whether it was as closely guarded by rangers during the 2007 study. It may be that the increased human traffic in this area has led to increased levels of *E. coli*.

Water sourced from Bushokoro Well may also be picking up bacterial contaminants along the distribution pipeline. While there was more often a decrease in indicator concentrations between the park source and the first tap (Site 6) along the Bushokoro pipeline, there was generally an increase from Site 6 to the second tap along the community pipeline (Site 7). As noted, the pipe was visibly broken in several locations and may thus be exposed to numerous sources of contamination, such as runoff with animal feces. Observations of the area during water testing noted that livestock, such and cows and goats, were commonly herded up the ravine where the broken pipe was located. Fecal matter from these animals grazing along the path where the pipes are located may be seeping into the system. There is also significant human traffic along this route, including young children. Any open defecation in the area may cause contamination of the water in the pipeline via runoff entering points where there are breaks.

Overall, this study could not establish a correlation between weather conditions and water quality at any of the sources. Water quality testing was conducted primarily at the beginning of the dry season in Rwanda. As a result, variability in water quality between seasons could not be addressed. Weather conditions were largely the same throughout the testing period. However, one occurrence of rainfall occurred during the testing period, on the night of June 25. The water samples taken from the Bushokoro Well in the park on the next day, June 26, had a concentration of 362.4 MPN/100 ml, which was the highest concentration of *E. coli* seen in samples from that source during the study period and the highest concentration of *E. coli* detected in samples from any of the water sites during the study period. An increased concentration of *E. coli* (216.0 MPN/100 ml) was also detected in samples from Site 6, one of the community taps connected to Bushokoro, though this was not the highest concentration detected at that site during the study period. Previous research has found that heavy rainfall occurrences contribute to increased fecal contamination in source water [25]. During periods of drought that are followed by heavy rain, the rainfall may cause fecal matter in the surrounding environment to flood into water sources, thus increasing their overall levels. The event during this study consisted of heavy rainfall that lasted several hours from the late afternoon to night-time. This rainfall was a rare occurrence for the dry season in Rwanda, and had occurred after several weeks of dry weather. As such, the sudden rainfall may have resulted in the spike in *E. coli* contamination seen in samples from the two Bushokoro water points on the June 26 testing date. However, our study did not have multiple sample collections after events of rainfall to draw a conclusive effect between rainfall and contamination. Further, it is unclear why increased levels of contamination were not detected in samples from other sites following the rainfall.

The study did not find a discernible pattern of temporal variability within each of the sources. This may have been due to the fact that there were only seven weeks of regular testing, with samples taken at each source only once per week. A study of river water in rural Ecuador found more variation on an hourly basis as opposed to a daily or weekly basis [25]. Some of this hourly variation in the Ecuador study was due to the fact that people waded directly into the river to collect water. Levels of *E. coli* contamination were thus higher during times of greater human activity around the river, specifically during the daytime. It is unknown whether similar patterns occurred in the Bisate water sites. Observations of the water taps in Bisate documented that children often sucked on the valves to increase the flow of water, but as there were no easily accessible wells outside the park, it would be difficult for area residents to have other physical contact with the water.

Despite our findings of contamination of numerous public water points in Bisate, a majority of survey respondents (about 67 percent) indicated that they had treated their water in the past month. Further, anecdotal reports from household survey respondents indicated that there was some knowledge within the community regarding which sources are considered as safe to utilize for drinking water. However, 35 percent of those who reported that they had not treated their water indicated that treatment was unnecessary or that the water was already treated. If those who do not treat their water obtain their water from sources contaminated with pathogens such as *E. coli*, they may be at risk for infection.

Our study also found that residents of the Bisate Catchment Area have access to treated water from standpipes. The water points managed by EWSA had central water treatment which at least included chlorination, at a location outside of Bisate before the water was piped into the community [10]. However, we found that the treatment may not be as effective as intended. Though almost all of the samples collected from taps operated by EWSA had a free chlorine residual, they did not generally meet international standards for treated water. Out of the seven taps tested, only two taps met the World Health Organization minimum chlorine residual standard for drinking water (0.20 mg/liter) and none met the standard for piped water distribution (0.50 mg/liter). The water from the EWSA taps was not free, and because it was chlorinated, it was considered to be clean by residents of the village [9]. As noted previously, household survey respondents indicated that a primary reason for not treating water was that it was already treated. This is consistent with the findings of a previous study conducted in Malawi, which found that households may assume that water obtained from a protected source is safe, and thus utilize water treatment methods less often [26]. It is unclear which water source these respondents utilized; however the low level of free residual chlorine in the EWSA taps may not protect the water from contamination in the pipeline or during customer transport and household water storage.

Water Source Accessibility

Mapping of the water points provided insight into household accessibility of water sources. Accessibility was defined in accordance with the World Health Organization definition of "reasonable access" to an "improved water source"; that is, living within one kilometer of a source that is "adequately protected from outside contamination, in particular, from fecal matter" [3]. We found that 84% percent of surveyed households had reasonable access to an improved water source. This statistic is also greater than the percentage of coverage currently estimated for the country of Rwanda on the whole. However, the topography of the Bisate region may pose an added challenge in reaching some water sources. Much of the Bisate Catchment Area is hilly and rocky; walking one kilometer uphill requires more kilocalories of energy than traveling the same distance on a flat road. Furthermore, the percentage of households calculated to have access to an improved water source is based only on our survey of 20 households in each village (with one village represented by 25 households). Numerous residences were excluded from this analysis, and therefore the proportion of households with reasonable access to an improved water point may be overestimated.

This estimate of access is further complicated by the types of water sources present in the Bisate Catchment Area. Of the twelve taps that were considered to be improved water sources, eight of the taps charged fees for usage. In 2011, the Rwandan government estimated that 48.7% of the rural population lived below the poverty line, the equivalent of 118,000 Rwandan francs (Rwf) per year or around 323 Rwf per day [56]. At 2014 exchange rates, this equates to earnings of about $0.48 per day. The Rwandan government also estimated that about 26.4% of the rural poor live in extreme poverty, earning less than 83,000 Rwandan francs per year, roughly 227 Rwf per day [56]. During the selection of households for the survey, village chiefs indicated that many of the village households suffer from poverty or extreme poverty. Thus, it is likely that many households in the Bisate Catchment Area may have difficulty paying to regularly obtain water from an improved water point.

In addition to income, households may have varying levels of accessibility to adequate water depending on family size. WHO also defines "reasonable access" as the ability to obtain 20 liters of water per person per day [5]. Complying with these guidelines would cost a family of four 60 Rwandan francs per day to obtain an adequate amount of water. If a household cannot afford to purchase water from the EWSA taps, members of that household are left with four free public taps to choose from, and these are predominantly situated in the center of Bisate. Our analyses of water samples from these four free public taps detected regular contamination of two of the taps. Therefore, we conclude that at the time of this study there were only two water taps with water that met WHO microbiological guidelines for drinking water and were free of charge in this region of 20,000 people.

Without the ability to access a clean source of water for free, poor households may be compelled to utilize the park sources. As it is punishable by law to enter Volcanoes National Park without a permit, villagers rarely admit to fetching water from within its boundaries. However, anecdotal reports by community members and respondents to the household survey (results not reported here) indicated that people were seen going into the park for water, especially during the dry season. Further, wait times for water may also influence decisions to use the less commonly frequented water sources that are located inside the park.

The results of this study indicate that there is a need for greater accessibility to improved water sources that meet WHO guidelines for microbiological water quality, as well as promotion of household water treatment to ensure residents are drinking safe water. Though there is "improved" access to water points within the Bisate Catchment Area, factors such as the hilly topography, wait times for water, and user fees may limit access to these points. Additionally, this study found that half of the free public water taps in the Bisate community had evidence of fecal contamination. Residents with knowledge of the contaminated water may consider the park water sources to be cleaner, and therefore a safer option. Thus, increased availability of clean water in the community may be necessary to discourage residents from using water sources inside Volcanoes National Park. Reduced human activity may decrease the risk of pathogen introduction into park water sources as well as the risk of human-animal pathogen transmission.

Strengths and Limitations

While water quality testing has been conducted in the Bisate Catchment Area, this analysis serves as an update and expands upon the results of the previous studies. To our knowledge, this is the first study that combines water quality data with household level data on water source accessibility in the Bisate Catchment Area. The increasing level of human-gorilla interaction that has occurred in Bisate as a result of eco-tourism and gorilla habituation provides further reason to study the public health implications of their overlapping habitats. Information from this analysis may be used to inform community health workers, development agencies, and conservation programs that seek to improve the health of the humans and the gorillas in Bisate.

The study was limited by several factors that affected our ability to draw deeper conclusions regarding water quality and access in the Bisate Catchment Area. Collection and testing of water samples was originally scheduled to occur during a ten-week study period that would have included the end of the rainy season and start of the dry season. This longer time period would have allowed greater assessment of variability in water quality between the seasons. However, research team schedules restricted the study period to a shorter time span than anticipated. Local regulations mandate that all visitors to Volcanoes National Park must have a permit and be escorted by park rangers. Scheduling rangers to escort the research member into the park took longer than anticipated and delayed the collection of water samples from the park sources. Furthermore, safety concerns surrounding a visit to the Bisate Catchment Area by the President of Rwanda resulted in the research team being unable to travel to the field for one week and further reduced the length of the study period. Due to these constraints, the research period was shortened to a total of seven weeks, which was entirely during the dry season.

Further research is needed to understand the factors that contribute to contamination of the Bushokoro Well and Myase Stream sources inside Volcanoes National Park. Due to park regulations, it is extremely difficult to get inside the boundaries without a permit, even as a researcher. For this study, a student from the National University of Rwanda was permitted to enter the park with DFGFI mountain gorilla trackers and sample the three sources inside the forest. Future researchers should consider partnerships with Rwandan institutions while conducting research, or seek permission from park authorities well before their data collection period.

There is also limited knowledge regarding the process by which the water supplied by EWSA is sourced and treated. Prior to the collection of field samples, team members met with a staff member from EWSA, who discussed the background of the EWSA tap project in the Bisate Catchment Area. However, full details of the project, including the source of the chlorine used for treatment and the water treatment location, were not provided. Follow up questions were not answered, and the information was not available on the EWSA website.

Water source accessibility calculations were constrained by the data collected. GPS points were originally collected with an intention of calculating distance between households and their most commonly used source of water. The research team utilized pictures of the various water sources when administering the household survey. Participants were asked to choose the photograph that represented their main source of drinking water. This data would have been useful to calculate the distance that residents generally travel to obtain water. However, there was some confusion among participants regarding the use of these photographs, as some participants felt that some of the water points looked similar to others. As a result, this information from the household surveys was not considered to be entirely accurate and was therefore not used to calculate distances to water. Instead, the water source proximity analysis was conducted according to the closest source of water.

An additional limitation that prevented an accurate calculation of the distance from each household to a respective water source (as opposed to the closest water source) was that no pathways were created by taking GPS points. Although ArcMap® has capabilities to calculate "least cost pathways" (routes with least resistance in terms of elevation and direction); these would have been conjectures, as there may have been a longer, yet more common path to each water source that was used by the residents of Bisate.

Finally, while the student research team attempted to sample the most commonly used water sources in Bisate, the some residents may have used other sources that were not accounted for in the survey and sample collection. During the household survey, some respondents indicated that they used sources such as the "Kazi River" or "Nyabageni Cave". As the research team was unaware of the existence of these water points, they were not included in the sampling plan. Thus, there may be households that had "reasonable access" to other water sources, although the quality of these sources was not determined.

Public Health Implications and Recommendations

The results of this study have numerous implications for the health of the Bisate residents, and broadly, for areas where there is increased human-animal contact.

In the community, rehabilitation of the Bushokoro pipeline may result in decreased contamination of the taps connected to this main water source. Though our study did not conclusively find a link between the broken pipeline and microbial contamination of the water, the increased concentration of *E. coli* and total coliforms from the first community tap to the second tap suggests that fecal contamination may be entering through breaks in the pipe. Replacement of the line with sturdier pipes that are placed deeper in the ground may provide better protection from erosion and human and animal activity.

Improved maintenance of the pipeline and water taps may also result in decreased contamination and better accessibility. At several points throughout the study period, community level interventions were observed in response to decreased functionality of water sources. Methods such as a funnel constructed from a leaf or a jerry can turned upside down on the pipe were used to collect optimal amounts of water from taps. When community members noticed that the pipeline was broken, temporary mitigation measures such as plastic wrap and rocks placed on the pipeline were taken, presumably to decrease water loss. In one case, a broken tap was quickly fixed on the same day it was noticed, although it was unclear who was responsible for the repair, and what was done to repair the tap. These observations indicate some community knowledge about the functionality of the water points, but there was no evidence to suggest that any one person oversaw management of the free public water taps. Training of a community water management team to facilitate repairs and provide general maintenance of the taps would allow rapid response to inevitable malfunctions of the taps.

As discussed, the Bisate Catchment Area receives a significant amount of rainfall, which is normally absorbed quickly into the soil. Despite this, there were very few rainwater catchment systems observed in Bisate during the study period. Other than the rainwater catchment system at the DFGFI trackers' house, the only other systems that were noted were located at a local school and church, and we were not permitted to collect samples from these systems. The rainwater catchment system found at the DFGFI trackers' house was generally free from bacterial contamination. Rainwater harvesting may be an efficient utilization of resources by the residents of the Bisate region, especially due to the high levels of rainfall that occur during the rainy seasons. Although the rainwater system we sampled generally had no bacterial contamination, a low level of contamination was found on two days (for unexplained reasons). Therefore, it may also be recommended to treat the harvested water in some manner, especially if it will be stored for some time.

In general, household water treatment should be recommended for the residents of Bisate, regardless of the source of water. Contamination of water may occur during transport or household storage, especially if poorly cleaned, open vessels are utilized for storage. As this study found, residual chlorine levels in the treated water sources were below WHO guidelines. Data from the household survey (results not reported in this paper) indicated that these sources were generally trusted amongst community members. As a result, water from these sources is not likely to have further treatment at home.

However, this water may be vulnerable to re-contamination during transport or storage due to the low chlorine residual.

To convey messages about water, sanitation, and hygiene (WASH), it is recommended that a comprehensive water, sanitation, and hygiene module be integrated into the Rwandan community health worker curriculum, especially for community health workers who live in rural areas such as the Bisate Catchment Area. During an interview with the coordinator of the community health worker program at the Bisate Clinic, it was indicated that a WASH module does not currently exist as part of the health education curriculum (results not reported here). By creating a standardized WASH module for the health workers, known as *animateurs*, consistent WASH messaging can be delivered to people across Rwanda. Once they are provided with a standard WASH curriculum, *animateurs* may also be able to tailor the messaging to their specific communities. This type of education program may also be useful to implement in local schools, where children could learn proper water treatment methods and bring the knowledge home to their families. As children are generally those who collect water in Bisate (results not reported here), it is important for them to understand methods of safe transport and storage that will prevent contamination of the water.

Overall, greater promotion of water treatment and increased availability of affordable safe water may decrease the risk of enteric infection in the residents of Bisate. This may also have an effect on decreasing the risk of enteric infection in the mountain gorillas of Volcanoes National Park. The recommendations from this study may be used to inform water quality and access intervention strategies aiming to improve the health of both humans and gorillas in Rwanda.

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Appendices

Appendix A: Emory University Institutional Review Board Exemption

EMORY UNIVERSITY | Institutional Review Board

Date: May 23, 2013

Christine Moe, PhD
Principal Investigator
Global Health

RE: **Exemption of Human Subjects Research**
IRB00065670
Baseline Assessment of Water, Sanitation, and Hygiene; Infectious Diseases; Community Demographics, and Livelihoods in the Bisate Catchment area, Rwanda.

Dear Dr. Moe:

Thank you for submitting an application to the Emory IRB for the above-referenced project. Based on the information you have provided, we have determined on 05/23/2013 that although it is human subjects research, it is exempt from further IRB review and approval.

This determination is good indefinitely unless substantive revisions to the study design (e.g., population or type of data to be obtained) occur which alter our analysis. Please consult the Emory IRB for clarification in case of such a change. Exempt projects do not require continuing renewal applications.

This project meets the criteria for exemption under 45 CFR 46.101(b)(2)(4). Specifically, you will be working as a multidisciplinary Global Health Institute team to look at factors affecting the overall health of the population, as well as those related to the community's use of the forest, land, rivers, and streams in and around the National Park. You are partnering with the Dian Fossey Gorilla Fund International (DFGFI), a major non-governmental organization working on gorilla conservation in the region since the mid-1970s, to conduct this assessment in order aid their efforts to sustain the gorillas and community itself. You will be performing interviews both at households as well as in groups, and will be observing and noting resources present in the community, especially in the households and at the health center. GPS points will be taken at important landmarks in the community to understand the layout and interactions taking place.

- Informed consent-Survey(Version: 05/08/2013)
- Informed Consent-Focus Groups (Version: 05/08/2013)
- Informed Consent-Health Care Interview (Version: 05/02/2013)
- Protocol document
- Surveys and Questionnaires:
    - Focus Group Topics
    - Healthcare Survey and questions
    - Household questionnaire

Please note that the Belmont Report principles apply to this research: respect for persons, beneficence, and justice. You should use the informed consent materials reviewed by the IRB unless a waiver of consent was granted. Similarly, if HIPAA applies to this project, you should use the HIPAA patient authorization and revocation materials reviewed by the IRB unless a waiver was granted. CITI certification is required of all personnel conducting this research.

Unanticipated problems involving risk to subjects or others or violations of the HIPAA Privacy Rule must be reported promptly to the Emory IRB and the sponsoring agency (if any).

In future correspondence about this matter, please refer to the study ID shown above. Thank you.

Sincerely,

Steven J. Anzalone, M.S.
IRB Research Protocol Analyst
This letter has been digitally signed

CC:	Berendes	David	Global Health
	Hennink	Monique	Global Health
	Nugent	David	Anthropology
	Shane	Andrea	Pediatrics
	Vazquez Prokopec	Gonzalo	Environmental Studies

Appendix B: Approval from the National Ethics Committee of Rwanda

REPUBLIC OF RWANDA/REPUBLIQUE DU RWANDA

NATIONAL ETHICS COMMITTEE / COMITE NATIONAL D'ETHIQUE

Telephone: (250) 2 55 10 78 84
E-mail: info@rnecrwanda.org

Web site: www.rnecrwanda.org

Ministry of Health

P.O. Box. 84

Kigali, Rwanda.

FWA Assurance No. 00001973

IRB 00001497 of IORG0001100

June 19, 2013
No.550/RNEC/ 2013

Dr. Christine Moe;
Felix NDAGIJIMANA
Principal Investigators

Your Project title: **"A BASELINE ASSESSMENT OF WATER, SANITATION, AND HYGIENE; INFECTIOUS DISEASES; COMMUNITY DEMOGRAPHICS, AND LIVELIHOODS IN THE BISATE CATCHMENT AREA, MUSANZE DISTRICT"** has been evaluated by the Rwanda National Ethics committee.

		Involved in the decision		
			No (Reason)	
Name	Institute	Yes	Absent	Withdrawn from the proceeding
Dr.Jean-Baptiste MAZARATI	National Referral Laboratory	X		
Prof. Eugène RUTEMBESA	National University of Rwanda	X		
Dr.Laetitia NYIRAZINYOYE	National University of Rwanda(school of public Health)	X		
Prof.Alexandre LYAMBABAJE	National University of Rwanda	X		

Ms.Françoise UWINGABIYE	Lawyer at Musanze	X		
Dr. Egide KAYITARE	National University of Rwanda	X		
Sr.Domitilla MUKANTABANA	Kabgayi Nursing and Midwife school		X	
Mr. David K. TUMUSIIME	Kigali Health institute	X		
Dr. Lisine TUYISENGE	Kigali Teaching Hospital	X		
Dr. Claude MUVUNYI	National Referral Laboratory		X	

After reviewing your protocol during the RNEC meeting of 08 June 2013 where quorum was met, and revisions made on the advice of the RNEC submitted on 14 June 2013, **Approval letter has been granted to your study.**

Please note that approval of the protocol and consent form is valid for **12 months**.
You are responsible for fulfilling the following requirements:

1. Changes, amendments, and addenda to the protocol or consent form must be submitted to the committee for review and approval, prior to activation of the changes.
2. Only approved consent forms are to be used in the enrollment of participants
3. All consent forms signed by subjects should be retained on file. The RNEC may conduct audits of all study records, and consent documentation may be part of such audits.
4. A continuing review application must be submitted to the RNEC in a timely fashion and before expiry of this approval.
5. Failure to submit a continuing review application will result in termination of the study.
6. Notify the Rwanda National Ethics committee once the study is finished.

Sincerely,

RWANDA NATIONAL ETHICS COMMITTEE
DATE 19/06/2013
COMITE NATIONAL D'ETHIQUE

Dr. Jean- Baptiste MAZARATI
Chairperson, Rwanda National Ethics Committee.

Date of Approval: June 19, 2013
Expiration date: June 18, 2014

<u>C.C.</u>
- Hon. Minister of Health.
- The Permanent Secretary, Ministry of Health.

Appendix C: Household Survey conducted in the Bisate Catchment Area, Rwanda, June-July 2013

WASH, Livelihoods, and Healthcare Survey, Rwanda GHI Project: Bisate Catchment Area

Date : ____ Cluster: _________________________________ GPS ID :_________________________________	Household Survey :____________________ Interviewer Number : ____________________ Respondent gave consent? ☐ Yes (*continue*) ☐ No (*skip household*)
1. *Sex* (***Check one***)	☐ Male ☐ Female
1a. Are you the primary person who collects water? (***Check one***) 1b. What is your marital status? (*Check one*)	☐ Yes ☐ No ☐ Single ☐ Married ☐ Widowed ☐ Divorced
2. How many people slept in this household last night? (***Fill in***)	_____________ people
2a. How many children 5 years old and younger slept in this household last night? (***Fill in***)	_____________ children
Livelihoods	
3. Do you or anyone in your household own a radio that is currently working? (***Check one***)	☐ Yes ☐ No ☐ Don't know
4. Do you or anyone in your household own a mobile phone that is currently working? (***Check one***)	☐ Yes ☐ No ☐ Don't know
5. Do you own agricultural land? (*Check one*)	☐ Yes *continue to Q5a* ☐ No *skip to Q6* ☐ Don't know *skip to Q6*
5a. If YES, about how much agricultural land do you own?	_____________HA
6. Do you rent land?	☐ Yes *continue to Q6a* ☐ No *skip to Q7* ☐ Don't know *skip to Q7*
6a. If yes, what is the payment?	☐ Sharecropping ☐ Fixed rent ☐ Don't know
7. How much livestock do you have and of what types? ***Fill in number of livestock next to type***	________ Cattle ________ Goats ________ Sheep ________ Pigs ________ Ducks ________ Chicken ________ Rabbits ________ Other: __________________
8. How much of the food consumed by your family is bought at the market? (***Check one***)	☐ None of it ☐ Less than half of it ☐ About half of it ☐ More than half of it ☐ All of it
9. What other activities do you engage in besides farming? (***Check all that apply***)	☐ Animal herding ☐ Manufacturing ☐ Work at health center ☐ Work for tourism ☐ Commercial work (store)

	☐ Civil servant ☐ Other:_________________ ☐ Only work as farmer_
10. Has your household, in your opinion, benefited from development projects in your area? (***Read and check all that apply***)	☐ Tourism ☐ Livelihoods projects ☐ Rainwater catchment projects ☐ Beekeeping ☐ Handicraft or other craft projects ☐ Other ☐ Did not benefit
11. Do you or someone from your household ever go into the forest? (***Check one***)	☐ Yes *continue to Q11a-b* ☐ No *skip to Q12* ☐ Don't know *skip to Q12*
11a. If YES, what is the main reason you or someone from your household goes into the forest? (***Check one***)	☐ To get water ☐ To get food ☐ To get other resources that can be sold at market ☐ To get wood ☐ Other:___________
12. Do people in your village ever go into the forest?	☐ Yes *continue to Q12a-b* ☐ No *skip to Q13* ☐ Don't know *skip to Q13*
12a. If YES, what is the main reason they go into the forest? (***Check one***)	☐ To get water ☐ To get food ☐ To get other resources that can be sold at market ☐ To get wood ☐ Other: ____________________
Healthcare Communication, Knowledge, and Practices	
13. Have you or anyone in your household spoken with or listened to a health animator or other community leader bearing health or hygiene messages in the last 3 months? (***Check one***)	☐ Yes → *continue to Q12a-b* ☐ No → *skip to Q13* ☐ Don't know → *skip to Q13*
12a. Was this a Health animator or a community leader or both? (***Check one***) 12b. Were any of these messages delivered to your household about diarrhea disease or hygiene? (***Check one***)	a. Health animator B. Community leader c. Both ☐ Yes ☐ No ☐ Not sure
14. What is the best way for you or someone in your household to receive important health or hygiene information? (***Read the list*** *and* ***circle one response***)	a. Doctor/nurse b. Health Animator c. Community Leader d. Traditional healer e. SMS f. TV g. Newspaper h. Printed flyers i. Radios j. Church k. Vehicle/person with megaphone l. Other: _________________________
15. Can you tell me all the ways that people can get sick with diarrhea?	a. Through drinking contaminated water b. Through eating contaminated or undercooked food

(***Do not read***, *allow respondent to list and* ***circle those that are listed***)	c. From unpleasant odors d. From flies landing on food e. From contact with someone sick with diarrhea or someone who died from diarrhea f. From swimming/bathing in surface water g. From contact with feces h. From (Kuvuma (when you do something bad to someone it allows them the ability to wish ill upon you.) i. Umuvumo- (A curse placed on you by the gods or the spirits) j. From poisoning (ie. a "traditional curse") k. Other: ___________________________ l. Don't know
16. Please tell me all the ways you know to protect yourself or your household from getting sick with diarrhea. (*Do not read, allow respondents to list symptoms and* ***circle those that are listed***)	a. Boil or treat your water/drink clean water b. Use latrines c. Wash hands with soap and water d. Cook food well e. Wash fruits and vegetables f. Cleaning cooking utensils g. Clean your home with bleach h. Dispose of children's feces in toilet/latrine i. Bury feces j. Receive a vaccine k. Store water safely l. Breastfeeding babies m. Other: _______________ n. Don't know any ways
17. Do you or those in your household seek healthcare from health centers, traditional healers, or others outside your household when you are sick or have a medical condition?	☐ Yes → *continue to Q16a* ☐ Sometimes → *continue to Q16a* ☐ No → *skip to Q17* ☐ Not sure → *skip to Q17*
16a. Where are the places that you or someone in your household has gone for healthcare in the past year? (***Read and circle all that apply***)	a. Bisate Clinic → *go to Q16b* b. Ruhungeri Hospital → *go to Q16c* c. A hospital in Kigali d. Traditional healer → *go to Q16d* e. Family member (grandmother) f. Other: _________________ g. Unsure
16b. If you or someone in your household visited the Bisate health center, what were all the reasons you/they went for? (***Read and circle all that apply***)	a. Diarrhea b. Malaria c. Typhoid d. Cough/respiratory illness e. Stomach ache f. Antenatal care g. Post-natal care h. Injuries i. Mental health j. Childbirth k. Vaccines l. Family Planning m. Nutrition n. Kuvuma (when you do something bad to someone it allows them the ability to wish ill upon you.) o. Umuvumo- (A curse placed on you by the gods or the

	spirits) p. From poisoning (ie. a "traditional curse") q. Other illness: _____________ r. Don't know
16c. If you or someone in your household visited the Ruhengeri Hospital, what were all the reasons you/they went for? (***Read and circle all that apply)***	a. Diarrhea b. Malaria c. Typhoid d. Cough/respiratory illness e. Stomach ache f. Antenatal care g. Post-natal care h. Injuries i. Mental health j. Childbirth k. Vaccines l. Family Planning m. Nutrition n. Kuvuma (when you do something bad to someone it allows them the ability to wish ill upon you.) o. Umuvumo- (A curse placed on you by the gods or the spirits) p. From poisoning (ie. a "traditional curse") q. Other illness: _____________ r. Don't know
16d. If you or someone in your household visited a traditional healer, what were all the reasons you/they went for? (***Read and circle all that apply)***	a. Diarrhea b. Malaria c. Typhoid d. Cough/respiratory illness e. Stomach ache f. Antenatal care g. Post-natal care h. Injuries i. Mental health j. Childbirth k. Vaccines l. Family Planning m. Nutrition n. Kuvuma (when you do something bad to someone it allows them the ability to wish ill upon you.) o. Umuvumo- (A curse placed on you by the gods or the spirits) p. From poisoning (ie. a "traditional curse") q. Other illness: _____________ r. Don't know
18. A. Do you have an illness or medical condition that you have currently had for over 3 months. B. Do you have an illness or medical condition currently that you have had for less than 3 months	a. Yes b. No a. Yes b. No
19. How often do you or your children seek care when you are sick with diarrhea?	☐ Always → *continue to Q18a* ☐ Sometimes → *continue to Q18a* ☐ Never → *skip to Q19* ☐ Not sure → *skip to Q19*
18a. Where do you go for care when you are sick with diarrhea?	a. Health center b. Local healer

	c. Family member (grandmother) d. Health animators e. Other: ________________ f. Unsure
18b What is the treatment	a. Medication from pharmacy b. Medication from traditional healer c. Powder to add to water (SRO/ORS) d. 'Special food' e. Other:____________________________ f. Unsure
18c. Where do you go when your child is sick with diarrhea	a. Health center b. Local healer c. Family member (grandmother) d. Health animators e. Other: ________________ f. Unsure
18d. What is the Treatment	a. Medication from pharmacy b. Medication from traditional healer c. Powder to add to water (SRO/ORS) d. 'Special food' e. Other:____________________________ f. Unsure
20. With what frequency do you or your children seek care when you have problems breathing or are coughing?	☐ Always → *continue to Q19a* ☐ Sometimes → *continue to Q19a* ☐ Never → *skip to Q20* ☐ Not sure → *skip to Q20*
19a. Where do you go for care when you are sick with a respiratory illness? 19b. Where do you take your children for care when they are sick with respiratory illness?	a. Health center b. Local healer c. Ruhengeri hospital d. Family member's (grandmother) e. Other: ________________ f. Unsure a. Health center b. Local healer c. Ruhengeri hospital d. Family member's (grandmother) e. Other: ________________ f. Unsure
21. Have your children received any vaccines?	☐ Yes → *continue to Q21* ☐ No → *skip to Q22* ☐ Not sure → *skip to Q22*
22. Did you experience barriers or difficulties when getting vaccines for your children? 21a. If yes, what types of barriers/difficulties?	☐ Yes → *continue to 22a* ☐ No → *skip to 23* ☐ Don't know → *skip to 23* a. No transportation b. Sickness of mother c. Health center didn't have vaccinations d. No mutuelle card

	e. Did not remember f. Do not trust vaccinations g. Other:___________________ h. Don't know
Hygiene	
23. Do you have any soap in your household?	☐ Yes → *skip to Q23* ☐ No → *continue to Q22a* ☐ Not sure → *skip to Q24*
22a. Why do you not have soap? (***Do not read, circle one***) **Go to Question 24**	a. Ran out of soap b. Cannot afford soap c. Soap is unnecessary d. Don't like soap e. Too far to walk to get soap f. Other:____________ g. Don't know

24. Can you please show me all of the types of soap that you currently have in the house? (***Mark one and Observe***)

☐ *Willing to participate* → ***go to Q23a*** ☐ *Refuse to participate* → ***go to Q24***

Type of soap	Bar soap (for toilet)	Large bar soap	Powder soap	LIQUID SOAP
a. ***Did respondent bring this type of soap? (Check one)***	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
b. What do you use the soap for? (***Circle all that apply***)	a. Hand-washing b. Bathing c. Washing dishes d. Washing clothes e. Other f. Don't know	a. Hand-washing b. Bathing c. Washing dishes d. Washing clothes e. Other f. Don't know	a. Hand-washing b. Bathing c. Washing dishes d. Washing clothes e. Other f. Don't know	a. Hand-washing b. Bathing c. Washing dishes d. Washing clothes e. Other f. Don't know

25. Can you please tell me when you think it is most important to wash your hands? (***Circle all that apply but do not prompt***)	a. Before eating b. Before cooking/meal preparation c. After defecation d. Before breastfeeding e. Before feeding children f. After handling a child's feces or cleaning a child's bottom g. Other: ________________________
26. When do you think it is not necessary to wear shoes?	a. In the house + around the home b. In the field c. I never wear shoes d. Unsure e. Other:
27. Do you think it is necessary to wear shoes in the latrine/when you defecate?	☐ Yes ☐ No ☐ Don't know.
28. Do you brush your teeth with a toothbrush?	☐ Yes ☐ No ☐ Don't know
29. Have you been to a dentist in the past year	☐ Yes ☐ No ☐ Don't know
Water Collection	
30. What has been your **one** main source of drinking water in the last week? (***Circle one but do not prompt with responses***)	a. Well with a handpump b. Open dug well c. Surface water outside park (ex. lake, river,

	unprotected spring) d. Surface water inside park (ex. lake, river, unprotected spring) e. Piped connection to house f. Public tap/Fountain → (*Show picture*) #________ g. Rainwater h. Other:____________ i. Don't know
31. How many times did you collect drinking water from this main drinking water source in the last day and with which containers? (***Show respondent images of containers and have them point out which ones they used and how many times, fill in***)	_____________times per day (to go for water) _____________20L _____________10L _____________5L _____________Other:_____________ _____________Other:____________
32. The last time your household collected drinking water from this main drinking water source, how long did it take to go to the source from your house (**<u>one-way</u>**)? (***Fill in/Circle***)	_____________minutes ☐ Don't know
33. A. On average, when you are at the main drinking water source you just told us about, about how long do you usually have to wait to collect water during the dry season? (***Check one***) B. On average, when you are at the main drinking water source you just told us about, about how long do you usually have to wait to collect water during the rainy season? (***Check one***)	☐ Less than 10 minutes ☐ 30 minutes to 1 hour ☐ 10 to less than 30 minutes ☐ More than 1 hour ☐ Don't know ☐ Less than 10 minutes ☐ 30 minutes to 1 hour ☐ 10 to less than 30 minutes ☐ More than 1 hour ☐ Don't know
34. Do you pay for your drinking water from your main source? (***Check one***)	☐ Yes → *continue to Q33a* ☐ No → *skip to Q34* ☐ Not sure → *skip to Q34*
33a. How much do you pay for 20 L of water from this main source? (***Fill in***)	____________Rwfs ☐ Don't know
35. Do you think water at the main source is safe to drink as is? (without treatment) (***Check one***)	☐ Yes, ~~all the time~~ → *continue to Q34a* ☐ Yes, sometimes → *continue to Q34a* ☐ No → *skip to Q34b* ☐ Don't know → *skip to Q35*
34a. Why? (***Circle all that apply but don't prompt***) ***Go to Q36***	a. I have no choice b. The water is treated c. The water is clear d. The water has no odor e. The water source is protected f. The water tastes good g. I pay for the water h. Other:__________ i. Don't know
34b. Why not? (***Circle all that apply but don't prompt***)	a. The water is not treated b. The water is cloudy/dirty c. The water smells bad d. The water source is not protected e. The water does not taste good f. The water is free g. Other:__________ h. Don't know
36. Aside from this main source you told me about, what other sources did you use for <u>drinking</u> water in	a. Well with a handpump b. Open dug well

the <u>last week</u>? (***Circle all that apply or "Did not collect from another source"***)	c. Surface water outside park (ex. lake, river, unprotected spring) d. Surface water inside park (ex. lake, river, unprotected spring) e. Piped connection to house f. Public tap/Fountain→ (*Show picture*) #________ g. Rainwater h. Other:____________ i. Don't know j. Did not collect water from another source
37. <u>In the last week</u>, when you are away from your house, where do you get water to drink? (***Circle <u>all that are mentioned,</u> but do not prompt with responses, prompt with 'anywhere else' after a response***)	a. Well with a handpump b. Open dug well c. Surface water outside park (ex. lake, river, unprotected spring) d. Surface water inside park (ex. lake, river, unprotected spring) e. Brings from house f. Public tap/Fountain→ (*Show picture*) #________ g. Rainwater h. Other:____________ i. Don't know
38. A. Do you or your household members drink water from inside the park during the dry season? (***Check one***) B. Do you or your household members drink water from inside the park during the rainy season? (***Check one***)	☐ Yes ☐ No ☐ Don't know ☐ Yes ☐ No ☐ Don't know
39. A. Do members of your village drink water from inside the park during the dry season? (***Check one***) B. Do members of your village drink water from inside the park during the rainy season? (***Check one***)	☐ Yes ☐ No ☐ Don't know ☐ Yes ☐ No ☐ Don't know
40. Where do you get the water to <u>wash your dishes</u> or <u>cook</u> or <u>to wash your clothes</u> from? (***Circle <u>all that are mentioned,</u> but do not prompt withresponses, prompt with 'anywhere else' after a response***)	a. Well with a handpump b. Open dug well c. Surface water outside park (ex. lake, river, unprotected spring) d. Surface water inside park (ex. lake, river, unprotected spring) e. Piped connection to house f. Public tap/Fountain g. Rainwater h. Other:____________ i. Don't know
<u>Water Treatment</u>	
41. Have you treated water in your household in the <u>past month</u>? (***Check one***) *Treating consists of boiling, filtering, disinfecting, and/or other actions to 'clean' water.*	☐ Yes ⟶ *continue to Q40c-e* ☐ No ⟶ *continue to Q40a-b* ☐ Don't know ⟶ *skip to Q41*
40a. **If NO**, when was the last time you treated your water?	☐ 1 to less than 2 months ago ☐ 2 to less than 3 months ago ☐ 3-6 months ago

	☐ More than 6 months ago ☐ Never
40b. **If NO**, why have you not treated it since then? *Check all that apply* ***Skip to Question 41***	☐ Ran out of water treatment products ☐ Cannot afford water treatment products ☐ Cannot find water treatment products to buy ☐ Water treatment products are unnecessary ☐ Don't like the taste of treated water ☐ Could not get wood to boil water ☐ Other:____________ ☐ Don't know

40c. In the past month, (***Read all and circle one response for each***)

a. Did you boil your water?	Yes / No / Don't know
b. Did you filter your water?	Yes / No / Don't know
c. Did you treat with tablets, liquid, or powder	Yes / No / Don't know
d. Did you do anything else?	Yes / No / Don't know
d1. If YES, what? _________________________	

40d. If YES, what are all the things that you used the treated water for in the last month? (***Circle <u>all that apply</u> but do not prompt with responses***)	a. Drinking b. Cooking c. Washing dishes d. Cleaning/Bathing/Hand washing e. Other: ____________________ f. Don't know
42. When do you think it is necessary to treat your water? (***Circle all that apply but do not prompt with responses***)	a. All the time/always before drinking b. Only after/during rain events (storms, cyclones) c. When there are reports of waterborne disease d. When a CHW/brigadier/health professional tells me to e. When I have treatment product/when it was given to me f. Only when water is dirty g. Other: ________________________ h. Don't know

<u>Water Collection and Safe Storage</u>

43. Can I see the main water container where you ***<u>store</u>*** drinking water in? (***Check one***)	☐ Yes ⟶ *continue to Q43* ☐ No ⟶ *skip to Q49*

Use reference chart to note the following:

	Size	Volume
44. *Type of container where water is currently stored* (***Choose one***) 45. *Volume (L)* (***Choose one or circle 'unable to observe'***)	a. Bucket b. Jerry Can c. Other:_________	a. Less than 20L b. 20L c. Greater than 20L
46. *Is it covered?* ***(Circle one)***	Yes / No	
47. *Is there a narrow neck/opening?* ***(Circle one)***	Yes / No	
48. *Does it have a tap?* ***(Circle one)***	Yes / No	

<u>Sanitation</u>

49. Can I see the latrine where you usually defecate? (***<u>Observe</u> and record***)	☐ Yes, latrine is present → *continue to Q48a* ☐ No, they go in the open → *skip to Q49* ☐ No, they refuse to participate → *skip to Q48e*

OBSERVATION SECTION

48a. *Type of Structure* ***(Circle one)***	a. Flush or pour/flush toilet b. Pit latrine c. Composting toilet d. Ventilated improved pit latrine e. Bucket toilet f. Other: ___________ g. None, open defecation or plastic bags used

48b. *Does it look like the latrine is in use?* (***Circle one***)	☐ Yes ☐ No ☐ Don't know
48c. *Condition of Area Surrounding Structure*	
a. Is the path to the structure blocked or impeded in any way? (***Circle one***) b. Is there a hand-washing area near the latrine? (***Circle one***) i. If YES, is soap present? (***Circle one***) ii. If YES, is water present? (***Circle one***)	Yes No Not Sure Yes No Not Sure Yes No Not Sure Yes No Not Sure
48d. *Condition of Structure*	
a. What kind of slab is present? (***Circle one***)	a. Wood e. Other:__________ b. Logs f. None c. Plastic g. Don't know d. Concrete
b. What is the superstructure made of? (***Circle one***)	a. Fabric e. Thatch b. Metal f. Other:___________ c. Wood g. None d. Concrete
c. Is there a cover for the drophole? (***Circle one***)	Yes No Not Sure
d. Is there a noticeable smell inside the structure? (***Circle one***)	Yes No Not Sure
e. Is there visible waste present on the slab or inside the structure? (***Circle one***)	Yes No Not Sure
f. Is there a door or some privacy cover for the latrine? (***Circle one***)	Yes No Not Sure
g. Is there a roof for the latrine? (***Circle one***)	Yes No Not Sure
48e. Is the latrine for your family or do you share it with others in the community? (***Check one***)	☐ Private ☐ Shared
48f. How many people use this latrine? (***Fill in***)	________________ people
48g. Is there anyone in the house that doesn't use the latrine? (***Circle one***) 48g.1. If YES, why? (***Fill in***)	Yes No Not sure ____
48h. Who is in charge of cleaning and/or maintaining the latrine? (***Circle one but do not prompt***)	a. No one cleans and/or maintains the structure b. Me c. A member of my family d. My neighbors e. Other f. Don't know
50. Are there times when you cannot use a toilet? (***Check one***) 49a. If yes, when? (***Check all that apply***)	☐ Yes → *continue to Q49a* ☐ No → *skip to Q50* ☐ Don't know → *skip to Q50* a. In the field b. At the market c. At church d. When I travel e. When I go to the forest f. Other: ________________ g. Don't know
51. Have you or someone in your household been trained in how to build a latrine yourself? (***Check one***)	☐ Yes ☐ No

	□ Don’t know
52. Has someone you know outside of your household been trained in how to build a latrine? (***Check one***)	□ Yes □ No □ Don’t know

End of Survey