

Drinking water quality and source reliability in rural Ashanti region, Ghana

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ABSTRACT

Site-specific information about local water sources is an important part of a community-driven effort to improve environmental conditions. The purpose of this assessment was to gather this information for residents of rural villages in Ghana. Sanitary surveys and bacteriological testing for total coliforms and *Escherichia coli* (EC) using Colilert® were conducted at nearly 80 water sources serving eight villages. A focus group was carried out to assess the desirability and perceived quality of water sources. Standpipes accounted for almost half of the available water sources; however, a third of them were not functioning at the time of the survey. EC bacteria were found in the majority of shallow wells (80%), rivers (67%), and standpipes (61%), as well as 28% of dug wells. Boreholes were free of EC. Residents felt that the standpipes and boreholes produced safe drinking water. Intermittent service and poor water quality from the piped supply has led to limited access to drinking water. The perception of residents, that the water from standpipes is clean and does not need to be treated at home, is particularly troubling in light of the poor bacteriological quality of water from the standpipes.

Key words | bacteriological quality, community-based participatory research, drinking water, Ghana, intermittent supply, standpipe

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INTRODUCTION

Inadequate access to water and poor water quality are primary causes of death in less resourced countries (Bartlett 2003; World Bank 2003). An estimated 88% of the burden of disease from diarrhea is attributable to 'unsafe drinking water supply, inadequate sanitation, and poor hygiene' and is one of the top three causes of child death in the world (Curtis & Cairncross 2003; WHO 2012). Other infections related to fecal-oral pathogens are also common in these regions; this may be due to the lack of availability or access to clean water, contamination of drinking water

sources, contamination of water during transport and storage, poor hygiene, and inadequate excreta disposal practices (Prüss *et al.* 2002; Schmidt *et al.* 2009).

Fecal-oral related infection rates are consistently high in Ghana and the surrounding region (Water and Sanitation Program 2011). In 2008, 68% of deaths in children under the age of five were due to infectious disease, 15% caused by diarrheal disease (Black *et al.* 2012). Overall there were 5,193 deaths attributable to diarrhea in the Ghanaian population of approximately 22 million people (Black *et al.* 2012). In Ghana the under-five mortality rate due to diarrheal disease is 12.2% (USAID 2007), about half the rate in the rest of

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sub-Saharan Africa (UNICEF 2001; WHO 2005b; Bosch-Pinto 2008; World Bank 2008). Moreover, the 2005 under-five mortality rate in the African region was reported by the WHO to be seven times higher than in the European region (WHO 2005b).

In recognition of the central role that access to sufficient amounts of high quality water plays in health, and to address the trend towards privatization of a limited resource, several countries at the 2009 World Water Forum proposed that water be considered a basic human right; a move that was opposed by Canada, Russia, and the United States (The PLoS Medicine Editors 2009). Improving water and sanitation has been stressed in the Millennium Development Goals (MDG), particularly in Goal 7 with a target to 'Halve by 2015, the proportion of persons without sustainable access to safe drinking water and basic sanitation' (National Development Planning Commission Ghana, April 2010). The MDG for water in Goal 7, reaching 89% of people worldwide with access to safe drinking water, was recently met (United Nations Millennium Campaign 2012). However, worldwide averages mask disparities in water availability and millions continue to lack access to water (UNICEF & WHO 2012). According to WHO and UNICEF, as of 2008 only 60% of the population in sub-Saharan Africa had access to improved sources of drinking water; a figure much lower than the world average of 87% (WHO & USAID 2010).

Ghana has better access to improved water sources than many sub-Saharan African countries, and has seen significant improvements over the last decade. Between 1995 and 2010, 42% of Ghanaians have gained access to improved water sources; currently 86% of Ghana has access to an improved water source (UNICEF & WHO 2012). 'Improved water sources' are defined as those that ensure suitable quality of water, including water supply piped into a dwelling or yard, a public standpipe, a borehole, a protected dug well, a protected spring, and rainwater (WHO & USAID 2006). Between 2000 and 2012, users of improved water sources in the urban population increased from 87 to 91% (WHO & USAID 2010). In the same period of time, the proportion of users of improved water sources in the rural population increased dramatically from 58 to 80% (UNICEF & WHO 2012), although an assessment by WaterAid in 2005 estimated a much lower level of coverage at 41% (WaterAid 2005). Even

so, insufficient supply of potable water remains a top concern of government leaders (Government of Ghana 2007; Awuah *et al.* 2009).

'Water piped on premises' is considered to be the highest level of water service. In Ghana only 30% of the urban population has this level of service, however this is nearly double the coverage for sub-Saharan Africa as a region (WHO & USAID 2010). As in many low-resource countries, there are significant operational problems with piped supplies. For example, WaterAid reports that nearly 50% of the produced water is unaccounted-for (WaterAid 2005). In Accra, approximately one-quarter of the population has 24-hour water service, 30% have 12-hours of service 5 days a week, and 35% have water service only 2 days a week (WaterAid 2005). The WHO Water Supply and Sanitation Assessment in 2000 reported that all piped water systems in Ghana were 'intermittent', providing water less than half the time (WHO 2000). Low or negative pressures in the distribution system during service interruptions can lead to contamination of the supply from intrusion of sewage or contaminated standing water (LeChavallier *et al.* 2005; Hunter *et al.* 2009; Elala *et al.* 2011; Huang *et al.* 2011). While only a small proportion (3%) of rural residents have water piped into their premises, there are some 800 small piped systems in rural areas of Ghana (WaterAid 2005). However, there is little readily available information about the reliability or water quality of these systems.

The Barekese sub-district, located in the Atwima Nwabiagya District of the Ashanti region in Southern Ghana, has a history of limited and unreliable access to piped water. The district assembly reports that 80% of the population has access to safe drinking water and 33% of residents have access to safe toilet facilities (Atwima Nwabiagya District 2006). Low sanitation rates within the district may be associated with the high rates of diarrheal diseases; the district reported 8,626 cases of diarrhea in 2009 among its estimated population of 180,000 (Atwima Nwabiagya District 2006).

In 2003 the University of Utah partnered with community members in the rural Barekese sub-district, the Komfo Anokye Teaching Hospital (KATH), the Kwame Nkrumah University of Science and Technology (KNUST) and the Atwima Nwabiagya District Assembly to form the Barekuma Collaborative Community Development Project

(BCCDP) (BCCDP 2009; de Schweinitz *et al.* 2009; University of Utah 2010). The BCCDP uses the principles of community-based participatory research (CBPR) to develop projects that improve the community's health. To date, the BCCDP has worked within the Barekese sub-district to reduce the burden of infectious disease and has adopted the Integrated Management of Childhood Illnesses as an approach (BCCDP 2009; de Schweinitz *et al.* 2009). Collaborators from the BCCDP have identified inadequate access to high quality drinking water and poor sanitation as high priorities.

As part of the planning and engagement process, an assessment was carried out to document existing water infrastructure, determine the reliability of water sources, assess the water quality available for domestic use, and evaluate community awareness as related to water, sanitation, and hygiene. This information will act as a basis for discussions between community members and key stakeholders within the BCCDP to address future education and infrastructure planning.

METHODS

This community water assessment was carried out in eight of the 20 villages of the Barekese sub-district. These villages were selected because (a) village leaders and residents expressed concerns about availability and quality of water and (b) they had been active participants in other BCCDP projects during the previous 6 years. Data were collected in three rounds as part of a University of Utah student field experience. During the summers of 2008, 2009, and 2010, field teams consisting of graduate and undergraduate students from the University of Utah and local guides identified water sources in each village with the assistance of residents. Each water source was assigned an identification number and documented using a digital camera. Locations were established using a Garmin[®] GPS. A sanitary survey was conducted at each source using a standardized instrument (Appendix 1, available online at <http://www.iwaponline.com/jwh/011/104.pdf>).

The sanitary survey included the water source type; construction materials/method; presence of a cover, pump, and public bucket; presence and condition of an apron; presence

of standing water around the well; and the location and distance to the nearest latrine. Latrines within 10 m were considered to be 'close' to the water source. Residents using the source at the time of the visit were asked whether they thought the water was potable and whether they drank the water. For standpipes, users were also asked how frequently water was available and at what cost. Dug wells depths were estimated based on the length of chain needed to lower the sample collection bucket.

The amount of time that the standpipes provided water was determined through conversations with standpipe users and villagers who lived close to the standpipes, key informant interviews with village leaders, and one focus group of village women. Criteria for assessing reliability included: (1) functioning at time of visit; (2) length of time since water was last available; and (3) the number of hours/days that water was typically available per week. A focus group comprised of a convenience sample of 11 local women was held in one of the central villages to gather information about perceptions of water quality.

During the summer of 2010, field teams also collected water samples from a sub-set of water sources. Two testing methods were used. Standpipes, which were expected to deliver high quality water, were assessed using the 100 mL Colilert[®] presence-absence test (IDEXX; Westbrook, Maine). The other water sources were expected to produce poorer quality water. As such the Petrifilm[™] enumeration method test was used (3M[™]; St Paul, Minnesota). This method allows one to determine the number of colony forming units (CFUs) in a 1 mL sample.

Sterile techniques were used to collect all water samples. For standpipes, the opening was first cleaned with an alcohol wipe, water was allowed to run for about a minute, and then a sample was collected by inserting a sterile 100 mL sample bottle containing a de-chlorinating agent into the water stream. Samples were transported to Kumasi where Colilert[®] medium was added to each bottle, bottles were inverted several times to dissolve the media, and then incubated at 35 °C for 24 hours (± 2 hours). Samples were then compared to a standard provided by the manufacturer. For interpretation of Colilert[®], yellow color indicated the presence of total coliforms (TC) and fluorescence under an ultraviolet light indicated the presence of *Escherichia coli* (EC) (IDEXX Laboratories 2012).

Water was collected from shallow wells, dug wells, and the river using an open stainless steel container and chain, which were sterilized by flaming before being lowered into the well. Water was collected from boreholes by cleaning the spout with an alcohol wipe, pumping 1–2 gallons, and then inserting the sterilized container under the water stream. One milliliter of water was extracted from the steel container using a sterile, disposable pipette. As per the method provided by the manufacturer, the protective top film of the Petrifilm™ EC plate was peeled back, the sample was deposited onto the medium, the top film was carefully rolled over the sample, and the sample was allowed 1 minute to gel (Vail *et al.* 2003; 3M 2011). It was then put in a Ziploc bag. At the end of the day, samples were incubated for 24 hours (± 2 hours) at 35 °C. Incubation times and temperatures were recorded at the beginning and end of incubation. Trapped gasses under the clear top film differentiated coliforms and *E. coli* from other forms of growth. Blue colonies with evidence of gas production were counted as EC; red and blue colonies that produced gas were counted as TC.

One focus group was conducted during the 2010 fieldwork. Eleven women from a medium sized village participated. It was facilitated by the first author and translated by a local fieldworker.

All data were entered into an Excel® spreadsheet, and analyzed using Stata® version 9 (College Station, TX). This

study was approved by the Institutional Review Board of the University of Utah (Study #IRB_00015866) and the Kwame Nkrumah University of Science & Technology School of Medical Sciences/Komfo Anokye Teaching Hospital, Kumasi (CHRPE/110/10).

RESULTS

Drinking water sources

Overall, 226 water sources were surveyed in eight villages over the course of 3 years. The types of source available varied considerably among villages (Table 1).

The largest villages rely primarily on standpipes and dug wells. While the estimated population of the villages ranges from about 300 to more than 4,500, the number of persons per functioning water source was relatively uniform.

Sanitary surveys were completed for 89 boreholes, dug wells and shallow wells (Table 2). Boreholes were generally in good condition; 86% had concrete aprons in good repair and good drainage around the wellhead (Figure 1). These boreholes were installed by the government and the depths were not recorded.

The dug wells ranged in depth (to water table) from approximately 3 to 25 m. The depths of dug wells were estimated: 45% at 3–10 m depth, 34% at greater than 10 m, and

Table 1 | Distribution of water source type by village

Village	Population	Standpipes <i>n</i> (%)	Standpipes without water ^a (<i>n</i>)	Boreholes <i>n</i> (%)	Dug wells <i>n</i> (%)	Shallow wells <i>n</i> (%)	River <i>n</i> (%)	Total water sources ^c	Persons per water source
Village 1	4,565	46 (56%)	4	2 (2%)	29 (35%)	4 (5%)	1 (1%)	82	56
Village 2	2,739	18 (33%)	13	3 (5%)	34 (62%)	0 (0%)	0 (0%)	55	50
Village 3 ^b	1,793	0	0	5 ^b	1 ^b	4 ^b	0	n/a	n/a
Village 4	1,133	11 (58%)	2	1 (5%)	5 (26%)	1 (5%)	1 (5%)	19	60
Village 5 ^b	715	^b	^b	0	2	0	0	n/a	n/a
Village 6	671	0 (0%)	18	1 (17%)	4 (67%)	0 (0%)	1 (17%)	6	112
Village 7	611	4 (44%)	0	1 (11%)	1 (11%)	0 (0%)	3 (33%)	9	68
Village 8	336	0 (0%)	0	2 (33%)	0 (0%)	0 (0%)	4 (67%)	6	56
Total	12,563	79 (42%)	37	15 (8%)	76 (40%)	9 (5%)	10 (5%)	189	57

^aStandpipes were defined as without water when residents assessed that they could not reasonably use or depend on this water source. These are separate from the standpipes, and not included in the total number of water sources.

^bIncomplete data for this water source.

^cThis number does not include standpipes without water.

Table 2 | Characteristics of water sources

Characteristics	Borehole (n = 14)		Dug well (n = 66)		Shallow well (n = 9)	
	n	%	n	%	n	%
Source covered	14	100	61	92	4	44
Source has apron	12	86	52	79	2	33
Apron cracked	0	0	20	38	2	67
Standing water present	3	21	12	18	6	67
Latrine near source (<10 m)	5	36	37	56	3	33

21% at greater than 3 m with exact depth not recorded. Almost all dug wells were protected with a cover (92%). The majority of dug wells had concrete aprons (79%); however, the apron was severely cracked in more than a third (38%). Public buckets were common (81%), but few dug wells were fitted with hand pumps (9%) (Figure 1).

A number of very shallow wells were also used as sources of drinking water. These were virtually surface water sources, with water levels less than a half of a meter from ground level and small walls around the perimeter

**Figure 1** | Examples (clockwise from top left) of a standpipe, borehole, shallow well, and a dug well in the Barekese sub-district, Ghana.

(Figure 1). Only two of the nine shallow wells had aprons, and most had standing water around the well.

Standpipes were present in five of the eight villages surveyed. The water supply for the distribution system serving these standpipes is the municipal treatment works at the Barekese Dam, which also serves the city of Kumasi. While there were more standpipes than any other source of water, nearly a third of these were not functioning at the time they were visited. They were reported to provide water so infrequently that nearby residents did not consider them a source of water. For example, one village elder reported that there had been no water from the standpipes in his village for the past six months. In another village, the standpipes did not flow for weeks to months, but occasionally would deliver high flows during sleeping hours. One village had 18 standpipes, none of which were working; as a result, residents are dependent on the few boreholes, dug wells, and river sources available. Water service consistently stopped when electricity was interrupted, and generally was less apt to be available at the higher elevations in each town.

Bacteriological water quality

Bacteriologic testing was carried out on 78 of the 226 water sources that had been identified in the eight villages (Table 3). Of functioning standpipes, all 18 were positive for TC, and nearly two-thirds (61%) were positive for EC. To assess the temporal variability, two standpipes were sampled multiple times on 4 days over a 9-day period,

Table 3 | Number and percent of water samples positive for total coliforms and *E. coli*, by water source type^a

Source type	<i>n</i>	Total coliforms, <i>n</i> (%)	<i>E. coli</i> <i>n</i> (%)
Standpipe ^b	18	18 (100%)	11 (61%)
Borehole ^c	10	1 (10%)	0 (0%)
Dug wells ^c	39	34 (87%)	11 (28%)
Shallow wells ^c	5	5 (100%)	4 (80%)
River access points ^c	6	6 (100%)	4 (67%)
Overall	78	64 (82%)	30 (38%)

^aDoes not include follow-up samples conducted on sub-sample of sources.

^bPresence/absence test – Positive indicates growth in 100 mL sample.

^cEnumeration test – Positive indicates 1 or more CFU observed in 1 mL sample.

using the Colilert[®] presence/absence (P/A) test ($n = 7$ samples taken from each). All samples were positive for TC. EC were present in 3 of 4 days for one standpipe, and 2 of 4 days for the other. When multiple samples were taken on the same day, the results were identical.

Boreholes delivered the highest quality water by far, with only one of the 10 boreholes (10%) positive for TC (1 CFU/1 mL) and no observed EC colonies. Given these results, we conducted simultaneous 100 mL Colilert[®] P/A test and 1 mL Petrifilm[™] enumeration tests on four boreholes. While all 1 mL Petrifilm[™] results were negative for TC and EC, three of the 100 mL Colilert[®] P/A test samples were TC-positive, and one of these was also EC-positive. This suggests that a greater proportion of the boreholes would have been positive if the 100 mL P/A test had been used.

Most of the dug wells were TC positive (87%), with a third having more than 10 colonies in the 1 mL sample (>10 CFU/1 mL). EC colonies were recovered from 28% of the wells; more than 10 CFUs were observed in only two of the samples. All of the samples from the river water access points and the shallow wells had high levels of TC (>10 CFU/1 mL). EC colonies were present in five shallow wells and one of six river access points.

Community members' perceptions and concerns

The focus group was conducted in a village where standpipes accounted for over half of the potential sources of water and dug wells accounted for a third. The participants of the focus group overwhelmingly believed that the piped water was the best quality and safe to drink. Many of the women stated that they did not treat standpipe water at home because it had been treated at the water treatment plant. However, most felt they could not rely on the standpipes as they would stop working for weeks or months at a time. When the standpipes were not working, the women reported that they had to walk much further to fetch water, either from dug wells or the river, even though they recognized that the water from these sources was not good to drink. Further, many expressed that they often did not have sufficient water for household uses. Many reported joint pain from years of hauling water on their heads.

Some women felt that the water from the standpipes was too expensive and many households were unable to afford the cost. While there were no boreholes in their village, most of the women believed that boreholes would provide clean water that was affordable and more reliable than standpipes.

DISCUSSION

Water sources and quality

The results of this assessment are consistent with findings from other studies in rural areas of low-income countries. As expected, all the river and shallow wells tested had TC present, and tested positive for EC 75% of the time. Dug wells were contaminated somewhat less frequently, with TC and EC detected in 87 and 28% of the samples, respectively. Most boreholes were well protected and provided good quality water; only one of the 10 sampled was positive for TC. Similar findings have been reported in other areas of Africa (Springer Science Business Media 2005; Mkandawire & Banda 2009; Ince *et al.* 2010). The impact of the enumeration method on the results is discussed below.

The piped water system in this region had serious deficiencies. A third of the standpipes were not producing water at the time they were visited. This appears to be a common problem throughout Africa. The 2000 WHO/UNICEF Assessment found that for half of the countries in Africa, 30% or more of their piped water systems were considered to be 'intermittent' (i.e. operating less than 50% of the time) (WHO & USAID 2000). All of Ghana's piped water systems were rated as 'intermittent'. There are few other assessments of the conditions of piped water system in Africa. Rietveld *et al.* (2009) conducted an assessment of piped water systems in 10 villages in South Africa and found that four had continuous service during the previous month, four had 1–4 days of no service, and the remaining two systems had not operated for 7 of the previous 30 days (Rietveld *et al.* 2009).

Several studies have documented intrusion of contaminated standing water into a distribution system through leaky joints or faulty valves when water pressure in the system becomes low or negative (WHO & USAID 2000;

Teunis *et al.* 2010; Besner *et al.* 2011). Low or negative pressures may be caused by illegal connections, breaks in the distribution system, changes in elevation of the distribution system, or a lack of supply due to lack of power or pumping malfunctions (LeChavallier *et al.* 2003; Andey & Kelkar 2009; Hunter 2009; Rietveld *et al.* 2009; Teunis *et al.* 2010; Besner *et al.* 2011; Huang *et al.* 2011). Studies in the USA, UK, and Norway found low-pressure events and problems in the distribution system to be associated with waterborne outbreaks, and that the duration of low or negative pressures was associated with the rate of waterborne illness (Nygård *et al.* 2007; Hunter 2009; Teunis *et al.* 2010; Besner *et al.* 2011; Huang *et al.* 2011).

In the present study, every operating standpipe was contaminated with TC and over half were positive for EC. A study in Cape Coast, Ghana, had similar results; all samples contained TC and 44% contained EC (Quagraine & Adokoh 2009). The source of piped water for the villages in our study was the municipal treatment plant for the city of Kumasi. While there are no data documenting the microbiological quality of the source water, the intermittent supply of water for the standpipes and poor state of the distribution system were likely contributing factors to the poor quality of water delivered by the standpipes. These results support guidance provided by the WHO that 'all intermittent water supplies should be assumed to be contaminated and measures taken to disinfect it at the point of use' (WHO 2005a).

These results highlight some of the problems that can occur when piped water systems are introduced before there is capacity to reliably provide high quality water. Of particular concern was the finding that residents believed the standpipes to produce the highest quality water. This may influence residents to use the standpipes rather than boreholes, increasing their risk of disease. Further, the presence of a piped water system, regardless of its reliability or water quality, may give the impression to government agencies or non-governmental organizations that water needs in the area are being met and no further investment is required. In this particular case, 'sharing' a supply with a metropolitan area leads to *de facto* competition between the interests of the urban area and the interests of a smaller, less-visible rural population.

The existing water system has great potential for reducing the use of highly contaminated water sources in these

villages. While a detailed spatial analysis of water source access was not carried out, standpipes were the most prevalent source of drinking water. Improving the system so that it produces high quality water would certainly reduce exposure for many of the residents. Improving reliability so the piped system operates a majority of the time would provide an alternative to river collection points and shallow wells that should be a 'last resort' for drinking water; this would further reduce the number of people exposed to contaminated water (Kimani-Murage & Ngindu 2007). For example, in Village 6, none of the 18 standpipes were functioning. Other available sources to serve the village's 671 residents included only one borehole, three river access points and one dug well. In Village 2, almost half (13 out of 31) of the standpipes were not working. Therefore 18 functioning standpipes, three boreholes, and 34 dug wells served the village's 2,739 residents.

Options for moving forward

Given the results of this assessment, a variety of approaches should be considered by the BCCDP. Repairing the piped water infrastructure and modifying operation to ensure continuous flow of water could provide high quality water to many residents who are currently using contaminated sources. This strategy would leverage investments already made in constructing the system. Despite the fact that standpipes have been viewed as the best source of water, governmental barriers will not be easily addressed in the near future. Providing an adequate amount of water that serves both the urban and rural areas may well be a substantial challenge, considering the rapid growth of urban populations in Ghana. Disinfection at the standpipe would help to address the water quality aspect, but would not address issues of reliability.

A more immediate need is community education. Women in the focus group mostly understood that water from the river and the shallow wells was not clean. However, they believed the standpipe water was superior to all other sources. Further dissemination of results from this assessment will help in efforts to educate residents about the water quality of the rivers, shallow and dug wells, and piped water system. This effort should encourage the use of the existing boreholes where they are available. The

focus group participants who used the river or shallow wells did so because they felt they had no other viable choice of water source. Providing convenient alternative water sources will be necessary to reduce the use of these traditional sources (Shier *et al.* 1996). Installing boreholes in areas where highly contaminated sources are the only option would be an important step to pursue. Additional testing should be conducted to identify areas where the groundwater is free from microbial contamination, and where existing wells produce high quality water.

Given the scarcity of sources that provide high quality water and ubiquitous problems with contamination during transport and household storage, household water treatment may be a necessary component of the BCCDP's efforts. There are a variety of beneficial and cost-effective options for household water treatment that have the potential to decrease diarrheal disease, including filtration and chlorination of drinking water (Wright *et al.* 2004; Hunter 2009; Clasen *et al.* 2010; Elala *et al.* 2011). Such point-of use interventions are limited in that they focus on only a single fecal-oral transmission pathway and lack benefits beyond improving water quality in the home (Prüss *et al.* 2002; Wolf-Peter & Cairncross, 2008; Schmidt *et al.* 2009). Furthermore, observed reductions in diarrheal diseases from household water treatment interventions may be due to bias. Chlorine is readily available in this area and clay pot filtration (i.e. ceramic water filtration) may be a viable option since water is already commonly stored in similar vessels. Qualitative research by the collaborative would be useful to assess the acceptability of any point-of-use method, and would help identify barriers and facilitators affecting choice of water source. As in other similar settings, comprehensive efforts to improve sanitation and hygiene will be needed to substantially reduce the risk of fecal-oral diseases (Prüss *et al.* 2002; World Bank 2003; Hunter 2009; Majuru *et al.* 2011).

Strengths and limitations

The primary purpose of this work was to provide clear information about the health risks of current water sources. This information can be used to guide community-directed actions to improve water quality and decrease risks of water-borne disease. Elements that strengthened this study by

ensuring sound data collection and better response from participants include: community support for the effort, collaboration in the planning of the study, the use of local interpreters, systematic training of team members, and consistent methods for conducting the sanitary surveys. This helped to ensure that we identified a large proportion, if not all, of the water sources in the villages. Our conclusions about the reliability of the piped water system were strengthened by having multiple sources of information (i.e. direct observations, key informant interviews and a focus group). In addition, one of the methods used to assess water quality is well-established (i.e. Colilert[®] P/A), while the other (Petrifilm[™]) has been shown to have a high degree of concordance with another approved method (Chuang *et al.* 2011). This is discussed in more detail below.

The primary limitation as a community assessment is that only a sub-set of the boreholes, standpipes and dug wells were sampled. This limited our ability to assess the associations between the source attributes captured by the sanitary survey and their microbiological quality. The sampling methodologies used were also a limitation. The use of the 100 mL Colilert[®] P/A testing for the standpipes provided a high sensitivity with a level of detection of 1 CFU/100 mL, but limited our knowledge of the degree of contamination. While the Petrifilm[™] method provided counts of TC and EC organisms in the other types of water sources, the use of only 1 mL of sample provides a detection limit of only 100 CFU/100 mL; TC or EC concentrations below this level would likely produce null results. This is a serious limitation as TC concentrations above 10 CFU/100 mL or EC levels above 1 CFU/100 mL are cause for concern (WHO 2008).

When using the Petrifilm[™] method, only one of the 10 boreholes sampled in our study was positive for TC and none was positive for EC. However, when the Petrifilm[™] and 100 mL Colilert[®] P/A methods were used simultaneously for four boreholes, all four of the 100 mL Colilert[®] P/A samples were TC positive and two were EC positive while none of the Petrifilm[™] samples grew any colonies. This illustrates the difficulty in comparing results from two methods that assess the presence of organisms using very different volumes of sample. In a recent study, the Petrifilm[™] method had high concordance with the Quanti-Tray[®] method (assessed as presence/absence), with a

sensitivity of 89% and a specificity of 85%, so the method itself appears to identify TC or EC when they are present in the 1 mL sample (Chuang *et al.* 2011). However, the analysis did not assess the sensitivity or specificity of the Petrifilm[™] method when indicator organism concentrations were less than 100 CFU/100 mL. The results from our small comparison study suggest that the detection limit for the Petrifilm[™] method may be too high (100 CFU/100 mL) to correctly determine the presence of indicator organisms in sources that are not heavily contaminated, i.e. between 1 and 100 CFU/100 mL.

CONCLUSION

The purpose of this assessment was to collect information that can guide the collaborative process for improving drinking water and health in the eight study villages. Site-specific data are essential for informing community-driven development efforts and these are the first readily available studies on bacteriological water quality in the rural Barekese sub-district in Ghana. Overall, there were few sources that provided potable drinking water. As expected, unprotected water sources (i.e. rivers, shallow wells and dug wells) were frequently contaminated. While boreholes provided high quality water, there were only 10 boreholes among the 89 functioning sources of water. The piped water system, which included 116 standpipes, was unreliable. Nearly a third of the standpipes did not have water at the time of the survey; the remaining standpipes had intermittent service. All of the standpipes were positive for TC, and over half contained EC.

Women who participated in a focus group and various key informants generally understood that the river and shallow wells were unsafe to drink from, but those who used them felt that they were the only accessible sources. Water from the standpipes was believed to be of the highest quality.

These findings reveal the technical, economic and behavioral challenges that face the BCCDP in its effort to collaboratively address the lack of safe drinking water. Findings from this study have been shared through community meetings and have generated interest in several potential courses of action. These include education efforts to promote the use of boreholes, finding partners to help install

more boreholes in areas where there are no safe sources of water, petitioning the government for improvements in the reliability and quality of the piped water system, and beginning a comprehensive health promotion campaign focused on household water treatment, safe water storage, hygiene education, and sanitation improvement. As structural improvements to the piped water infrastructure and installation of new boreholes will take time and significant resources, household level treatment should be considered as a more immediate intervention.

Collaborative efforts, such as this assessment, have built strong relationships between researchers, professionals, and residents participating in the BCCDP. Water and sanitation issues will continue to be evaluated by the BCCDP through the process of CBPR. Within its scope, the BCCDP will continue monitoring water quality in wells and the piped supply. Additional research needs to be conducted to understand the problems underlying the intermittent service and poor quality of the piped water supply. In addition, qualitative inquiries need to be conducted to better understand the attitudes and beliefs of the residents concerning drinking water and health, as well as the determinants of their choice of water source.

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