Access to Safe Water in Rural Artibonite, Haiti 16 Months after the Onset of the Cholera Epidemic

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Abstract. Haiti has the lowest improved water and sanitation coverage in the Western Hemisphere and is suffering from the largest cholera epidemic on record. In May of 2012, an assessment was conducted in rural areas of the Artibonite Department to describe the type and quality of water sources and determine knowledge, access, and use of household water treatment products to inform future programs. It was conducted after emergency response was scaled back but before longer-term water, sanitation, and hygiene activities were initiated. The household survey and source water quality analysis documented low access to safe water, with only 42.3% of households using an improved drinking water source. One-half (50.9%) of the improved water sources tested positive for *Escherichia coli*. Of households with water to test, 12.7% had positive chlorine residual. The assessment reinforces the identified need for major investments in safe water and sanitation infrastructure and the importance of household water treatment to improve access to safe water in the near term.

INTRODUCTION

Haiti has the lowest improved water and sanitation coverage in the Western Hemisphere by a significant margin[1] and is currently suffering from the largest cholera epidemic on record.[2] As of April 14, 2013, there had been 653,789 cases and 8,066 deaths reported from cholera.[3] Although the introduction of cholera into Haiti was unexpected, the poor water and sanitation infrastructure in addition to other well-known risk factors, such as poverty, high population density, and lack of immunity, facilitated its spread throughout the country.[4] Between 1990 and 2011, Haiti has made only small gains in increasing access to improved drinking water infrastructure. (The World Health Organization [WHO]/United Nations Children's Fund [UNICEF] Joint Monitoring Program [JMP] measures progress to the 2015 Millennium Development Goals related to drinking water and sanitation. Target 7C aims to halve the proportion of the population without access to safe drinking water and basic sanitation, and it is measured using a proxy of improved water and sanitation infrastructure and a baseline year of 1990.) Nationally, access to improved drinking water sources increased from 61% to 64%, but in rural areas, access actually decreased from 51% to 48%.[1]

Increasing access to safe drinking water is one of the priorities to reduce transmission of cholera and other waterborne illnesses. As part of the response to the October of 2010 cholera outbreak, the Government of Haiti and other agencies initiated country-wide efforts focusing on hygiene promotion and increasing access to treated water in an attempt to reduce transmission. These efforts included chlorination of public drinking water systems and mass free distribution of water treatment products to treat household water for those people unable to access piped chlorinated water. In the first year of the cholera response, it is estimated that over 100 million water purification tablets were distributed.[5] Surveys conducted after these distributions reported high awareness and reported use

of these products. In a November of 2010 Knowledge, Attitudes and Practices (KAP) survey in Artibonite, reported use of water purification tablets increased from 29% before the outbreak to 87% 1 month after the outbreak.[6] A national survey conducted by Population Services International (PSI) in early 2012 found that almost all respondents (87%) had treated their water at some point during the last 12 months, with most (92%) having used a solid chlorine product (e.g., tablets).[7] Additionally, families gained exposure to multiple water treatment products because of overlapping of distributions as well as individual purchases of products in the market. In a September of 2011 survey in Northwest Department, the majority of households (81%) reported using two or more water treatment products within the previous year.[8]

Because the number of cases has decreased, the Government of Haiti and other partners have shifted efforts to longer-term cholera prevention measures in Haiti. A critical objective of these efforts is to increase the sustainable access to safe drinking water, especially in rural areas. In May of 2012, the US Centers for Disease Control and Prevention (CDC) conducted an assessment in the rural sections of Artibonite Department. This department was chosen because of the high number of cases and fatalities related to cholera.[9] The assessment was conducted after emergency response efforts had scaled back but before initiation of longer-term water, sanitation, and hygiene (WASH) activities. The major objectives of the assessment were to describe the type and quality of water sources used by rural households in Artibonite and determine knowledge, access, and use of household water treatment products to inform current and future household water treatment and safe storage (HWTS) programs in the region.

METHODS

This assessment included two components: (1) household survey and (2) water quality analysis of drinking water sources identified during the household survey.

Household survey. The sampling frame for the household survey consisted of all households in rural Artibonite Department as listed by the Institut Haitien de Statistique et d'Informatique (IHSI). The 2011 IHSI figures are based on a 2009 census and

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adjusted for population growth and movement after the January of 2010 earthquake. The IHSI list consists of enumeration areas (EAs), with population generally between 200 and 1,500 persons. EAs are categorized further into either rural or urban entities. According to IHSI statistics, Artibonite Department consists of 2,059 EAs and 1,478,515 total persons. The population defined as rural consists of 1,621 EAs and 1,005,417 persons (68% of the population).

The household survey consisted of 40 clusters (EAs) of 12 households, each for a sample size of 480 households. This survey was based on an expected prevalence of 50%, with a 5% margin of error for access to drinking water treatment products and access to an improved water source. We oversampled by 20% to account for difficulties in reaching selected clusters and completing all households within a cluster. The 40 clusters were randomly selected from the list of rural EAs using probability proportional to size (PPS) sampling, and therefore, all households had an equal chance of being selected. The 40 rural EAs selected from the IHSI listing were plotted and enumerated in Google Earth (Google Inc., Mountain View, CA). Household enumeration consisted of counting and marking visible roofs on the Google Earth image; all of the satellite images were from 2010 or newer. On arrival at the cluster, team leads used a combination of global positioning system (GPS) orientation (Garmin GPSMAP 76CSx; Garmin International, Inc., Olathe, KS) and Google Earth satellite images (showing enumerated households) to locate households within the EA. The shape files for each of the selected EAs were downloaded to each GPS unit so that they could be located precisely. Within each cluster, 12 households were selected using systematic random sampling, such that the entire EA was covered. Households were replaced with an adjacent household if the respondent was unavailable or the house was abandoned. The preferred respondent in the household survey was the female head of the household and/or the person responsible for water collection if at least 16 years of age (the legal age of consent in Haiti). Oral consent was obtained before proceeding with the interview.

The survey instrument consisted of questions regarding household demographics, preferred methods of communication for health messaging, access to modes of communication (e.g., radios and cell phones), cholera knowledge, and water collection, use, and treatment. Respondents were also asked about current water treatment practices, and a water test for free chlorine residual was conducted using portable test kits (CN-66 Color Wheel; Hach Company, Loveland, CO). The questionnaire was written in English, translated into Haitian Creole, and reviewed by local enumerators for errors. The questionnaire was piloted in an EA not selected for the survey and subsequently modified.

An Epi Info version 7 (CDC, Atlanta, GA) database was developed in French for data entry. All analyses, including χ^2 tests, were conducted in SAS version 9.3 (SAS Institute, Cary, NC). Data were weighted to account for unequal probabilities of selection. A two-stage weighting was applied; the first stage was based on the inverse probability of selecting a household within the selected EA using the Google Earth enumeration, and the second stage was based on the ratio of the planned and the actual number of households surveyed per EA.

Water quality analysis of drinking water sources. Water source sampling took place concurrently with the household survey. One water sampler, trained in sterile sampling techniques, worked with each survey team to collect water used for drinking by 12 selected households in each cluster. Therefore, the water sampler attempted to collect a random sample of drinking water sources used by the surveyed households. In some instances, selected sources could not be sampled, because there was insufficient time to walk to the source.

Water samplers were also trained to fill out a water source description form to allow consistent classification of the source type and time of sample collection. At each source, a 100-mL sample was collected using sterile techniques in Whirlpak bags containing sodium thiosulfate. The samples were stored on ice in coolers before microbiological analysis. Samples were delivered for analysis within 8 hours of collection. Sample blanks were carried in each cooler to test at least one time for potential contamination of samples during storage and transport.

Two laboratories were assembled to conduct the microbiological sample analysis at the end of each day. Water samples were analyzed for total coliforms and *Escherichia coli* using the Colilert/Quanti-Tray method (IDEXX Laboratories, Inc., Westbrook, ME). The Quanti-Tray 2000 provides bacterial counts as low as < 1 most probable number (MPN) per 100-mL sample and up to 2,419.6 MPN/100-mL sample. Samples were incubated in Boekel Digital Incubators (Boekel Scientific, Feasterville, PA) at 35°C (±0.5°C) for 24 hours. Laboratory blanks were performed each day in each laboratory (15% of total) for quality assurance and control (QA/QC) of analytical procedure; field blanks were analyzed for QA/QC of each water samplers' collection techniques and accounted for 5% of total samples.

WHO has developed health risk levels for categorizing concentrations of *E. coli* found in water sources. Analyses were performed with respect to these WHO categories of health risk level.[10]

The assessment protocol, including the household questionnaire, was approved by the National Bioethics Committee of Haiti's Ministry of Public Health and Sanitation. The protocol was also reviewed by the CDC and determined to be a nonresearch public health program activity.

RESULTS

A total of 37 of 40 clusters (90.2%) selected for sampling were reached, and 433 household interviews were completed in May of 2012. Time restrictions prevented 3 clusters from being reached and all 12 household interviews from being conducted in 3 of the other 37 clusters (11 of 36 households not interviewed). In total, 108 water sources or water points were sampled in 37 clusters. At least one water sample was taken in each cluster, with a maximum of six samples in a cluster.

Household characteristics. Of 433 respondents for household surveys, 88.4% were female. Respondent and household characteristics are summarized in Table 1. Approximately 60% of respondents reported having contact with a health worker in the last 3 months, of which 47% indicated that the health worker visited their household. The most commonly reported preferred mode for receiving health messages was radio (32.8%), with the majority (61.5%) of these responses from those individuals who owned a radio. Community health workers/brigadiers were the second most common response (26.7%) followed by doctors/nurses (11.5%), community meetings (10.3%), and church (7.5%). Trucks

TABLE 1

Respondent and household characteristics in rural Artibonite Department in May of 2012

Variable (n = 433)	Number (%)
Mean age (years) of respondent (range)	41 (16–90)
Respondent able to read Creole phrase	183 (42.4)
Mean household size (range)	5.3 (1–12)
Mean number of children less than 5 years in household (range)	1.0 (0–5)
Household owns functional radio	161 (37.8)
Household owns functional cell phone	295 (69.0)
Median number of water storage containers in household (range)	3 (0–25)
Household currently using 20-L bucket for drinking water storage vessel	349 (89.1)
Drinking water vessel covered	373 (91.9)
Drinking water vessel has a tap	66 (15.0)

with megaphones and short message service (SMS) were each preferred by less than 5% of respondents.

Cholera knowledge. Cholera knowledge was high, with a majority of respondents describing the roles of contaminated water in transmission and water treatment in cholera prevention. Almost all respondents (88.8%) agreed that cholera was preventable, and three-quarters of respondents could name the two most common prevention messages: treat drinking water (75.2%) and wash hands with soap and water (75.9%). The most common response for a way of contracting cholera was contaminated water (81.2%) followed by contaminated or undercooked food (70.9%). Other ways were answered much less frequently than these two responses; the next most common response was contact with someone sick with or who died of cholera at 7.0%. Slightly less than 5% (4.8%) of respondents did not know any ways that cholera was contracted.

Water source types. Respondents were asked about their current primary source and secondary sources for drinking water along with primary water source for washing dishes, cooking, and bathing. Surface water (defined as unprotected springs, river/canal, and unclassified surface water) accounted for 45.3% of respondents' primary drinking water source (Table 2). Public taps/fountains/kiosks and boreholes with handpumps were the most commonly reported protected source types. Sixteen (3.4%) respondents reported using private kiosks for drinking water; water vended at these kiosks is provided from private companies, which advertise treatment

TABLE 2

Primary drinking water source types accessed by households in rural Artibonite Department in May of 2012

Variable (n = 433)	Number (%)
Improved source	185 (42.3)
Public tap/fountain/kiosk	85 (17.5)
Borehole with handpump	58 (14.8)
Protected spring	20 (4.9)
Private kiosk (vended water)*	16 (3.4)
Piped water onto plot	6 (1.7)
Unimproved source	247 (57.3)
Unprotected springs	115 (26.5)
River/canal	17 (2.8)
Unclassified surface water	63 (16.0)
Dug well†	52 (12.0)
Undefined	1 (0.4)

*These sources were classified as improved given the use of improved sources for cooking and bathing by these households (JMP definition).
†Enumerators could not visit the source to determine if protected; therefore, these sources are classified as unimproved.

with reverse osmosis membrane filtration. These sources were classified as improved, because these households also reported use of improved water sources for cooking and bathing.[1] When all primary drinking water sources were classified according to the JMP definitions, 42.3% of households reported the use of improved sources.

Respondents were asked about consumption of river or canal water when away from the home (e.g., when working). Among respondents who did not report surface water as either their primary or secondary drinking water source (n = 236), 21.8% reported drinking river or canal water periodically. Among all respondents, 31.7% indicated periodic consumption of surface water when outside of the home.

As with drinking water source types, sources of water used for other purposes (washing dishes, cooking, and bathing) varied widely, and surface water was most commonly reported; approximately 50% of respondents listed using surface water for dishes/cooking, and 60% used surface water for bathing. Many respondents listed multiple source types for these other purposes.

Microbiological quality of drinking water sources. Of 108 water samples taken, 55 (50.9%) samples were from improved sources, and 53 (49.1%) samples were from unimproved sources. Two-thirds of all samples (66.7%) were contaminated with *E. coli*, and 46.3% of all samples had an *E. coli* concentration greater than 10 MPN/100 mL (Table 3).

Both the improved and unimproved water sources showed a range of levels of fecal contamination, although a higher proportion of improved water sources had concentrations classified at lower risk levels. Approximately one-half (50.9%) of improved water sources sampled were positive for *E. coli*, and 23.6% had *E. coli* concentrations greater than 10 MPN/100 mL ($\overline{\chi}$ = 2.5 MPN/100 mL). For unimproved sources, 83.0% were positive for *E. coli*, with 69.8% of samples greater than 10 MPN/100 mL ($\overline{\chi}$ = 54.2 MPN/100 mL). A Pearson χ^2 test was conducted and confirmed a significant difference between the improved/unimproved source categories and presence of *E. coli* (P = 0.0004).

The source types tested with the best water quality were boreholes and private kiosks; 3 of 18 borehole samples were positive for *E. coli* ($\overline{\chi}$ = 0.7 MPN/100 mL). All six private kiosks were < 1 MPN/100 mL. All surface water (n = 6) and dug well samples (n = 14) tested positive for *E. coli*: $\overline{\chi}$ = 1,681.4 and 119.6 MPN/100 mL, respectively. The public taps/fountains/kiosks had a wide variability in water quality, with results in all five health risk categories; 78.6% of samples from this source type (n = 28) were positive for *E. coli* ($\overline{\chi}$ = 6.5 MPN/100 mL). The geometric mean *E. coli* concentration for each source type is shown in Table 4.

Perception of drinking water quality. Respondents were asked about their perception of the safety of their drinking water; 64.1% of respondents perceived their water source to be "safe as is." The perceived safety of different water source types used ranged from 56.3% to 68.2%, with the exception of private kiosk users, of whom 95.3% thought it was safe. Of 154 (34.2%) respondents who did not believe their primary drinking water source type to be "safe as is," the primary reasons were the water was not treated (86.2%), the source was not protected (16.6%), and the water did not taste good (9.3%).

Water collection practices and access. Adult females bore the brunt of water collection (81.1%), but both male and female children had water collection responsibilities (20.3%

TABLE 3
Water quality results according to WHO classification of health risk and source type in rural Artibonite Department in May of 2012

| Water source type | WHO risk level number (%) | | | | |
	Conformity (< 1 MPN/100 mL)	Low (1–10 MPN/100 mL)	Intermediate (11–100 MPN/100 mL)	High (101–1,000 MPN/100 mL)	Very high (> 1,000 MPN/100 mL)
Improved (n = 55)	27 (49.1)	15 (27.3)	8 (14.5)	4 (7.3)	1 (1.8)
Unimproved (n = 53)	9 (17.0)	7 (13.2)	14 (26.4)	9 (17.0)	14 (26.4)
Total	36 (33.3)	22 (20.4)	22 (20.4)	13 (12.0)	15 (13.9)

and 38.1%, respectively). An adult male was involved in water collection in 16.3% of households. Most respondents (62.4%) reported collecting water two or more times a day. Of those respondents who could estimate the time required for water collection, almost one-half (44.1%) reported being 5 minutes or less from the source, and 71.4% reported being less than 30 minutes from the source. One-quarter of respondents did not know the time to source (25.7%).

Household water treatment practices and preferences. Exposure to household water treatment products was high. The majority (80.5%) of respondents reported having treated their water in the past 3 months; however, 37.9% of those households (31.6% overall) had a water treatment product present at the time of the visit. Reasons for not treating water included an inability to afford the product/filter (45.8%) and a lack of access to the product (16.5%).

Respondents were asked about use of specific water treatment products and methods in the past 3 months. The most common household water treatment products used by households were disinfection products. In the last 3 months, 27.5% reported using two or more types of disinfection products. Sodium dichloroisocyanurate (NaDCC) tablets were the most commonly used product overall (Table 5). The majority (86.3%) of those individuals having treated water in the past 3 months did so in the form of Aquatabs (Medentech, Ltd., Wexford, Ireland; 69% overall). The 67-mg tablets were the most commonly used, but a range of sizes were reported (8.5, 17, 33, and 67 mg). PYAM tablets (Laboratorio Pyam S.A., Buenos Aires, Argentina) were used by 11.9% of households having treated in the past 3 months (8% overall). The other two most commonly used disinfection products in the last 3 months were liquid bleach (sodium hypochlorite, ranges from 5–15% active chlorine; locally branded as Jif or Clorox; 23.9% and 19% overall) and granular chlorine (calcium hypochlorite, ranges from 65–70% active chlorine; 9.4% and 8% overall). This concentrated form of granular high-test hypo-

chlorite (HTH) was not distributed for household water treatment as part of response efforts, but it has been adapted for this use and is locally sold in some markets in small quantities. The use of locally marketed dilute sodium hypochlorite products specifically designed for household water treatment (locally branded as Dlo Lavi, Gadyen Dlo, and Klorfasil) was reported by 11 respondents (3.0% and 2.5% overall).

Use of a combined flocculant–disinfectant powdered mixture (branded as PUR; Proctor and Gamble Company, Cincinnati, OH) was also reported by nine respondents. Filters were not commonly used among rural households in the last 3 months (12.3% and 10% overall); among filter users, biosand filters were the most common. Boiling was not asked as a potential water treatment method used in the past 3 months on the questionnaire.

Table 5 also contains the current water treatment products and methods reported by households at the time of the survey. The proportion of those households currently using Aquatabs, liquid bleach, and PYAM was lower than the last 3 months. Boiling was mentioned as a current method of water treatment by one respondent.

Approximately one-half of the respondents treating water in the last 3 months reported paying for a product (50.9%). Of those respondents that paid for a product, liquid bleach and granular chlorine were the primary products purchased (70.2% and 79.8%, respectively), but 42.3% of respondents indicated that they had paid for Aquatabs. Markets and non-governmental organizations (NGOs) were the most common sources for Aquatabs, which was closely followed by health facilities. Most respondents using liquid bleach or granular chlorine reported obtaining the product in the market (60.5% and 77.4%, respectively).

Most respondents (85.1%) cited disinfection as their preferred method of treatment; this method was followed by filtration (9.9%) and boiling (3.8%). These preferences matched previous reported use (Table 5), with the exception of boiling.

TABLE 4
Number of samples, *E. coli* positives, and geometric mean *E. coli* concentration (MPN/100 mL) by water source type in rural Artibonite Department in May of 2012

Water source type	Number (%)	*E. coli* positive number (%)	Geometric mean concentration	95% Confidence interval for geometric mean
Improved	55 (50.9)	28 (50.9)	2.5	1.4–4.4
Public tap/fountain /kiosk	28 (25.9)	22 (78.6)	6.5	2.6–15.9
Borehole with handpump	18 (16.7)	3 (16.7)	0.7	0.5–1.0
Protected spring	2 (1.8)	2 (100)	57.4	–
Private kiosk (vended water)	6 (5.5)	0 (0)	0.5	0.5–0.5
Piped water into plot	1 (0.9)	1 (100)	2.0	–
Unimproved	53 (49.1)	44 (83.0)	54.2	23.0–127.3
Unprotected spring	33 (30.5)	24 (72.7)	20.7	6.8–63.2
River/canal	6 (5.6)	6 (100)	1,681.4	646.0–4,377
Dug well*	14 (13.0)	14 (100)	119.6	31.3–456.9
Total	108 (100)	72 (66.7)	11.3	6.3–20.2

*Not sufficiently protected to be considered improved water sources.

TABLE 5

Previous (last 3 months) and current water treatment products used by households in rural Artibonite Department in May of 2012

Variable	Treatment product used in the last 3 months* (n = 351) number (%)	Current water treatment products used (n = 132) number (%)
Aquatabs (any size tablet)	305 (86.3)	73 (56.7)
Liquid bleach	78 (23.9)	16 (13.3)
PYAM tablet	44 (11.9)	5 (1.4)
Granular chlorine	35 (9.4)	11 (8.7)
Other disinfection products (Gadyen Dlo, Dlo Lavi, Klorfasil)	11 (3.0)	1 (0.8)
PUR sachets	9 (1.5)	–
Filters used	47 (12.3)	16 (10.9)
Other (unidentified)	5 (1.7)	9 (7.9)
Did not know	–	1 (1.0)
Boiled	–	1 (0.6)

*Multiple responses possible per respondent.

The most important reported reason for a preference, regardless of method indicated, was ease of use. The market was the preferred place to obtain household water treatment products (42.6%) followed by NGOs (21.9%), health facilities (18.0%), and community health workers (17.3%).

Knowledge of correct household water treatment methods. Respondents were asked to describe their water treatment practices. The results were analyzed as amount of product per 20-L bucket of water, given that most respondents stored drinking water in this vessel type (Table 1). Based on the manufacturer websites or specific dosage recommendations disseminated during the cholera response, the recommended quantity for each product was 67 mg of Aquatabs (e.g., one tablet of 67-mg size, two tablets of 33-mg size, etc.), 25 drops of liquid bleach (Jif or Clorox), two tablets (19 mg each) of PYAM, and two sachets of PUR. It was not possible to analyze dosage results for granular chlorine, because there was no standardized unit of measurement reported by households.

Reported dosing with the specific products used varied significantly, and the majority of respondents underdosed. Although just over two-thirds of all respondents reported use of Aquatabs in the previous 3 months, only 47% of these respondents knew what type of tablet they had used and/or had it in the home at the time of the survey. Approximately one-half (49.0%) of 143 respondents reported applying an acceptable dose (i.e., at least 67 mg); 25.0% of respondents underdosed, and 26.0% of respondents said they did not know how many tablets to use. Most of these respondents thought that one should put one tablet in one 20-L bucket, regardless of the tablet size. Of respondents reporting the use of liquid bleach in the last 3 months (n = 65), 15.9% reported the correct dose of at least 25 drops. Most of these respondents were underdosing (79.9%); three-quarters reported using five

TABLE 6

Chlorine residual levels at households with water available in rural Artibonite Department in May of 2012

Chlorine residual (mg/L)	All respondents with water to test (N = 328) number (%)	Among respondents treating current stored water (N = 131) number (%)	Among respondents treating water that day (N = 39) number (%)
0	281 (87.3)	92 (69.6)	22 (51.9)
0.1 to < 0.5	17 (5.0)	13 (10.5)	8 (24.3)
0.5 to < 2.0	17 (5.0)	17 (13.0)	4 (8.8)
≥ 2.0	9 (2.7)	9 (6.9)	5 (15.0)

or fewer drops (75.1%). All respondents using PYAM or PUR also indicated underdosing.

Chlorine residual testing. Among households with water available to test (n = 328), 12.7% of households had a detectable free chlorine residual result (Table 6). Among households reporting having treated the current water in the house (38.3%), 30.4% had detectable free chlorine residual. Free chlorine residual was also analyzed with respect to time of treatment. Of 27.1% of respondents who said that they had treated water on the day of the survey, 48.1% were positive for free chlorine residual.

DISCUSSION

The results of this assessment from May of 2012 document the low access to safe water in rural Artibonite and resulting high risk for continued cholera transmission. Information about access to safe water in the Artibonite Department is critical; to date, more than 100,000 cases of cholera have been reported from Artibonite, and this department has had the greatest number of fatalities related to cholera.[9] Based on our survey, use of improved water sources in this region is lower than the most recent estimate for both rural Haiti from JMP 2013 (48%)[1] and the whole of Artibonite Department (not just rural) from the Demographic and Health Survey (DHS) 2012 (49%).[11] Nearly one-half of this population reported collecting drinking water from unprotected springs, streams, canals, and rivers. Based on the estimated rural population of Artibonite Department, this result equates to over 450,000 people. With high rates of open defecation in rural Haiti,[1] the risk of surface water being contaminated with *Vibrio cholerae* and other waterborne pathogens is high. Furthermore, many of the improved water sources sampled were contaminated, suggesting that the proportion with access to microbiologically safe drinking water sources is lower than estimated by the JMP.

These findings contribute to an increasing body of evidence that shows that the classification of water sources as improved or unimproved is inadequate to measure access to safe water and that highlights the limitations of using this proxy alone.[12–15] Furthermore, most of the improved water sources currently accessed in rural Artibonite were located off-plot, meaning that water has to be collected, transported, and subsequently, stored in the home. In the absence of safe storage, these steps introduce the possibility of secondary contamination.[16,17] Finally, our results indicate that many of those individuals with access to an improved water source periodically consume river or canal water when outside the home. A recent article by Brown and Clasen[18] suggests that the health gains that could be realized with HWTS are seriously limited if even periodic consumption of unsafe water occurs.

Similar to other recent surveys, our findings indicate that the national cholera response efforts increased knowledge of cholera and awareness and use of various household water treatment products, most notably NaDCC tablets.[6–8,11] Although small-scale household water treatment projects and programs in Haiti have been operational for years,[19] the reported use of household water treatment since the start of the cholera outbreak is considerably higher than before.[20,21] However, important barriers for continuing HWTS promotion beyond emergency response were identified from this survey—namely, a lack of availability of water treatment products

after emergency response activities had scaled back, a lack of understanding of correct use of products reportedly used, and a lack of understanding of the importance of consistent use of treated water.

At the time of this survey, only about one-third of respondents had a water treatment product in the home. Lack of affordability and lack of access to household water treatment products were cited as barriers to consistent use, although notably, one-half of those respondents using treatment products in the last 3 months had purchased them. The reported lack of access to products is unsurprising given that mass distributions were largely of imported disinfection products, and this large-scale response effort had scaled back after the first 1 year of the outbreak.[5] Nevertheless, these barriers are clearly important barriers that need to be addressed as efforts shift to longer-term strategies.

Over two-thirds of the samples taken from reportedly treated and stored drinking water were negative for free chlorine residual. Our assessment revealed potential reasons for this finding. Extended storage time may have contributed to the loss of chlorine residual. However, lack of knowledge of correct use of the products was clearly a major contributing factor. Most respondents reportedly underdosed with the product that they used; this result was consistent across all types of products (liquid, tablet, and sachet). Incorrect dosage resulting from lack of sufficient education and training and confusion caused by use of multiple product types has been seen in other emergencies and may also apply to this situation.[22] Although turbidity was not measured during the assessment, anecdotally, it was reported to be low in the majority of the water available to test and therefore, not considered a factor contributing to reduction in chlorine residual.

Finally, our results indicate that there are still gaps related to understanding the importance of consistent use of treated water, including use when outside of the home. At the time of the survey, more than one-half of respondents perceived their drinking water sources to be "safe as is" without treatment. The survey took place at the end of the dry season, when there were fewer cases of cholera[23] and fewer response activities. Thus, there may have been a shift back to previous norms in terms of perceived risk regarding water source safety. Respondents who believed their water sources to be safe most commonly cited reasons of natural treatment, protection, and clarity. These beliefs are consistent with findings from other locations.[24] Thus, as a longer-term strategy, there may be a need to separate drinking water treatment from cholera prevention action and promote consistent use of treated drinking water. This situation has been seen during cholera outbreaks in Madagascar and Mozambique, with the initial rise and then fall in sales of household water treatment products after the outbreak subsided.[25,26]

This assessment had several limitations. First, 3 of 40 clusters were not reached during the survey, and 2 of these clusters were among the most remote in the department. Thus, access to improved drinking water sources and household water treatment products in these areas may have been different than access in areas included in the survey. Second, we were not able to collect samples for microbiological analysis from all water sources used by surveyed households. This limited our ability to make inferences about the water safety of specific water source types in this region. Although an

attempt was made to collect a representative sample, because of time restrictions, we slightly oversampled sources close to the homes of study participants, which may have been more likely to be improved sources, and likely undersampled sources that were farthest from the communities and may have been more likely to be unimproved. Third, reported treatment from boiling may have been underreported as a previous water treatment method, because interviewees were not specifically prompted about this method. Fourth, the results of this survey are representative of the rural population of Artibonite Department, and therefore, the results are not generalizable to all of Haiti.

In conclusion, this assessment documents the precarious situation facing households in rural Artibonite Department with respect to safe water supplies. It reinforces aspects of the newly published Government of Haiti National Plan for the Elimination of Cholera in Haiti 2013–2022 that calls for major investments in water and sanitation infrastructure as well as the importance of HWTS in rural Artibonite and presumably, other parts of Haiti to improve access to safe water in the near term.[27] The national cholera response increased the awareness and acceptability of household water treatment and created an opportunity to continue and scale-up HWTS promotion. Various strategies are needed to transition from emergency response to a development model of HWTS promotion. Our findings suggest that these strategies should aim to increase product availability and affordability, knowledge of correct use, and understanding of the importance of consistent and routine use. Previous research suggests that a comprehensive understanding of context-specific social, cultural, and behavioral factors will be foundational for household water treatment programs to advance in rural Artibonite and elsewhere in Haiti.[24] Finally, lessons learned in other settings indicate a combined approach involving partnerships between government, NGOs, and the private sector holds the most promise for scaling-up these necessary programs.[26,28–30]

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