Coupling microbiological testing and sanitary surveys in drinking water quality programs: results from Capiz Province, Philippines

J. Molly Patrick, Susan Murcott and Jarvis Punsalan

ABSTRACT

Developing countries often struggle to conduct laboratory-based water quality testing programs due to a lack of financial and technical resources. However, inexpensive, accurate, field-based tests are being developed which have the potential to overcome this barrier. This paper provides the results of an initiative by the Provincial Health Office in Capiz, Philippines, to conduct a first-ever, provincial, microbiological water quality test program. The effort was a collaboration with students from Massachusetts Institute of Technology, which aimed to identify sources most at risk, to test field-based analytical methods against standard methods, and to make recommendations for improving supplies in the short and long term. The microbiological, chlorine residual, and sanitary survey results are described in this paper. The results showed that there was an increasing trend in water quality from 'unimproved' to treated and/or piped supplies, but that many 'improved' point sources were contaminated. Less than 20% of the samples tested for chlorine residual were above the World Health Organization guideline. Sanitary surveys identified potential sources of contamination and were used to recommend priorities for remedial action. The implications of this work for other resource-limited areas are that microbiological testing and sanitary surveys are two essential components to assessing water safety and they should both be consistently applied in drinking water quality test programs.

Key words | drinking water, microbiological testing, point sources, sanitary surveys, water safety

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ABBREVIATIONS

DOH	Department of Health (Philippines)
DWP	Deep well pump
GPS	Gravity protected spring
HWTS	Household water treatment and safe storage
MIT	Massachusetts Institute of Technology
MPN	Most probable number
NGO	Non-governmental organization
PNSDW	Philippines National Standards for Drinking Water
PHO	Provincial Health Office
UN	United Nations
UNICEF	United Nations Children Fund
WHO	World Health Organization
WSP	Water Safety Plan

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INTRODUCTION

Drinking water quality testing and sanitary surveys are understood to be complementary activities; however, conducting these two activities in tandem has not been consistently applied in developing countries to date (Howard *et al.* 2003; Godfrey & Howard 2005). Taken together, these activities inform the necessary first steps to improving water safety (Howard 2003). Furthermore, they are both critical components of Water Safety Plan (WSP), which have been developed by the World Health Organization (WHO) to provide a 'comprehensive risk assessment and risk management approach' for ensuring the safety of a drinking-water supply system (WHO 2004; Davison *et al.* 2005).

Water quality testing creates accurate information regarding the quality of the drinking water, and sanitary surveys enable hazard identification (potential causes for contamination), along with an assessment of the level of risk for a particular water source (Lloyd & Bartram 1991). Both tools are reported by the WHO in terms of *health risk*; microbial drinking water quality results are in terms of the health risk due to a level of fecal contamination and sanitary surveys are in terms of health risk due to hazards (of microbial, physical, chemical, and radioactive origin) that '[…] pose an actual or potential danger to the health and well-being of the consumer' (WHO 1997).

Currently, the United Nations (UN) uses a proxy to indicate access to safe drinking water sources in Target 7c of the Millennium Development Goals. The sources are either defined as 'improved' (e.g. public taps, protected dug wells and springs, rainwater collection) or 'unimproved' (e.g. surface waters, unprotected dug well and spring, and vended water). Although the UN's indicators are easy to measure, they do not reflect the actual safety of the drinking water source. A better approach is to test drinking water quality. Laboratory testing is difficult in developing countries that often lack funds, technology, laboratory facilities, and trained laboratory personnel. However, over the past several decades scientists have developed a series of low-cost, field-based microbiological tests. A number of these tests have been validated against standard methods and have been recommended for use in microbiological water quality test programs in resource-limited areas (Nair *et al.* 1999; Vail *et al.* 2003; Clayton *et al.* 2010; Trottier 2010; University of Bristol 2010).

Sanitary surveys using simple templates developed by organizations such as WHO can be used at the community level to determine potential causes of contamination and to guide the subsequent implementation of control measures to decrease the risk of contamination. They require very little time and training to conduct, and are freely available from a variety of sources (WHO 1997; Davison *et al.* 2005).

In fall 2008, a collaborative effort to conduct a water quality test program using a combination of laboratory and field-based methods was undertaken by the Provincial Health Office (PHO) of Capiz Province, Philippines and a team from the Masters of Engineering program at the Massachusetts Institute of Technology's (MIT) Civil and Environmental Engineering department. This paper presents the laboratory results of the microbiological water quality and chlorine residual tests conducted from December 2009 to March 2010 on both 'improved' and 'unimproved' sources, as well as the results of sanitary surveys conducted during January 2010. The utility of conducting both of these activities is discussed based on the experience in Capiz. Finally, recommendations are made to guide efforts to improve water safety in the area.

Water quality initiative in Capiz Province

In 2008, the PHO in Capiz received funding from the European Commission, the Philippines Department of Health (DOH) and United Nations Children's Fund (UNICEF) to set up a microbiological water quality testing laboratory at Roxas Memorial Provincial Hospital, in Roxas City. The PHO sought advice from MIT to support the drinking water quality testing effort, specifically the type of water quality tests that should be performed and the overall research design. Quanti-Tray® was the recommended laboratory method by the MIT team. Quanti-Tray® was approved by the US EPA and is in use in more than 30 countries worldwide (IDEXX 2010a).

Funding supported only 1,000 microbiological tests, thus chlorine residual tests using the Hach® Free Chlorine Pocket Colorimeter II Test Kit were recommended for samples within the Roxas City drinking water treatment plant distribution system in order to make best use of the bacteriological tests on unchlorinated supplies.

From October to December 2009, in collaboration with the MIT team, the PHO developed a water quality assessment program designed to test 1,000 different water supplies from all 16 municipalities and Roxas City. The testing program started in December 2009. Fieldwork was conducted by the MIT team in January 2010, during which time sanitary surveys were conducted concurrently with water quality sampling.

MATERIALS AND METHODS

Capiz Province, Philippines

Capiz Province is a rural area located on the northeastern part of Panay Island, which is located in the Western

Visayas. It has a land area of approximately 2,600 km^2 and has roughly 80 km of coastline. The population has been estimated in 2008 to be approximately 701,000 (NSCB 2009). It is composed of 16 municipalities, 1 city (Roxas City) and 473 *barangays* (villages). The capital city, Roxas City, is located along the northern edge of the province and has an estimated population of 148,000. As the only urban area in the province, Roxas City is a center of trade and commerce, and as a result is becoming increasingly industrialized and commercialized. Fishing and farming are the major economic activities; which together use just over 50% of the total land area (Gov.Ph. 2009). The dominant agricultural crop is rice, but sugar cane, coconuts, bananas, and mangoes are also abundant. Freshwater and brackish water aquaculture, marine fishing and livestock production are all major industries in the area.

Water sources in Capiz

Until 2009, Capiz had never performed extensive drinking water quality testing on the various drinking water sources (wells, springs, surface water, and piped supplies) used throughout the province, with the exception of tests performed in the Roxas City water treatment plant. According to the National Statistical Coordination Board (2009) of the Philippines, as of 2000, 119,000 households in Capiz (or 92%) had access to an 'improved' drinking water supply (NSO 2002). The Capiz PHO, in common with the rest of the Philippines, currently uses four water source categories to designate their drinking water source types: Levels 1, 2, and 3, and Doubtful sources. (These designations and abbreviations, as defined by the Philippines government (DOH 1995), are used throughout this paper to describe water source categories and types.) Levels 1 through Level 3 sources fall under the UN's 'improved' category, whereas Doubtful sources are 'unimproved.' A summary of the Capiz and corresponding UN designations is presented in Table 1.

Table 1 | Capiz PHO water source designation and corresponding UN designation category

UN designation category	Capiz PHO designation Category	Source type
Improved	Level 3 (L3) (piped connection on premises)	• Water district • Local water utilities administration • *Barangay* (village) waterworks system
	Level 2 (L2)	• Gravity protected spring with pipe distribution to communal tap stands • Deep well with pump, with pipe distribution to communal tap stands
	Level 1 (L1)	• Shallow well pump • Jetmatic pump with or without motor • Deep well pump • Protected dug well • Protected spring without distribution • Rainwater catchment (ferro-cement tank)
Unimproved	Doubtful (D)	• Open dug well • Unprotected spring • Surface water (rivers, streams, creeks)

Sampling design

Both the water quality testing program and the sanitary surveys made use of a stratified sampling design. Samples were not randomly selected from the entire water source category spectrum, but were rather selected within each subpopulation. This means that a set number of samples per subpopulation (Doubtful, Level 1, Level 2, Level 3) were first determined, and then samples within each subpopulation were randomly selected for testing. The reason for this, as opposed to a purely random sampling program, was based on the overall study objectives of the PHO/MIT team, which was to make best use of limited test resources to identify sources most at-risk. Those goals were best accomplished by skewing the sample selection process towards Doubtful and Level 1 sources.

Microbiological tests

Water source type and location within each municipality had previously been recorded. The study design consisted of selecting one sampling zone for every 5,000 head of population (e.g. a municipality with a population of 30,000 would have six sampling zones selected). Within a given municipality, *barangays* were defined based on the ratio of water source types accessed by the residents and subsequently grouped into the respective subpopulations. The number of sampling zones to be drawn from each subpopulation was predetermined (e.g. one zone from Doubtful, three zones from Level 1, one zone from Level 2, one zone from Level 3), and *barangays* were then randomly selected for sampling.

Water source selection within zones was based on accessibility and their use by at least ten nearby households in the sampling zone. Table 2 shows the sample selection within zones.

The only exception to the aforementioned study design was the Level 3 water supply for Roxas City, Panay, Panitan, and Ivisan because these supplies are chlorinated. These samples were tested separately using chlorine residual testing instead of microbiological testing. This saved the more expensive bacteriological tests for sources expected to show bacterial contamination.

Chlorine residual tests

Sample locations from the distribution network in Roxas City and the Municipalities of Panay, Panitan and Ivisan, were tested for chlorine residual. Zones (*barangays*) were randomly selected from those being served by the distribution network in each municipality; the ratio of one zone for every 5,000 head of population was used. Five sampling sites (households) per *barangay* were selected to perform chlorine residual tests of Level 3 water supplies. The initial household was conveniently selected, and subsequent samples were acquired by visiting every tenth household to sample the piped water throughout the zone. In total, 85 samples were collected and analyzed: 50 in Roxas City, 15 in Panay, 15 in Panitan, and 5 in Ivisan.

Table 2 | Microbiological source and sample selection within each zone

Source type	No. of sources sampled	No. of samples/ source type	Source/sample selection
Doubtful	5	1	Random
Level 1	5	1	Random
Level 2	1	5 piped outlets	Random/outlets conveniently sampled
Level 3	1	5 household taps	Convenient sample/ systematic (every tenth household)

Sanitary surveys

In total, 52 sanitary surveys were conducted during January 2010. Level 1 and Doubtful sources were targeted for the surveys, which took place alongside the planned microbiological sampling program.

Test methods

Both field and laboratory-based microbiological tests were used during the test program. However, only the microbiological test results using Quanti-Tray® are included in this paper, and therefore will be the only method described. Results from the field-based tests can be found in Chuang (2010) and Trottier (2010). Sanitary surveys employed templates designed by the WHO (1997).

Quanti-Tray®

The IDEXX Quanti-Tray® is an enzyme-substrate coliform test (Standard Methods 9223) that uses semi-automated quantification methods based on most probable number (MPN). The enzyme substrate test uses hydrolyzable substrates for the detection of both total coliform and *E. coli* enzymes. When the enzyme technique is used, the total coliform group is defined as all bacteria possessing the enzyme β-D-galactosidase, which adheres to the chromogenic substrate, resulting in release of the chromogen (the sample changes color and becomes yellow). *E. coli* bacteria are defined as bacteria giving a positive total coliform response and possessing the enzyme β-glucuronidase, which adheres to a fluorogenic substrate and results in the release of the fluorogen, and hence causes the sample to fluoresce under UV light (APHA, AWWA, WPCF 2007).

The MPN method is an important quantitative tool in estimating the microbial population present in a water sample. It uses multiple qualitative (presence/absence) data points to generate a maximum probability coliform count per 100 mL value, given by a standard MPN table. The 51-well Quanti-Tray® system was used during the

Capiz laboratory analyses. The Quanti-Tray® provides bacterial counts (of total coliform and *E. coli*) as low as 1 MPN/100 mL and up to 200.5 MPN/100 mL of sample, and has a better than 95% confidence limit compared to multiple tube fermentation (IDEXX 2010b).

Chlorine residual

The Hach® Pocket Colorimeter II test kit is a portable device that can be used to detect the concentration of free chlorine residual in water. The device requires the addition of DPD (*N,N*-diethyl-*p*-phenylenediamine) free chlorine reagent to the sample to quantify the free chlorine residual concentration (Hach 2009). In the presence of chlorine, DPD reacts to turn the water sample pink. The sample, with the added reagent, is read by the device in comparison to a blank sample. The concentration level is determined using the Beer–Lambert Law, by measuring the absorption of wavelengths as light is passed through the sample. The range for measuring chlorine concentrations with this device is 0.1 to 10.0 mg/L. Concentrations found below this level may be inaccurate, but still indicates very low concentrations of free chlorine if not the entire absence of free chlorine.

Sanitary surveys

Sanitary surveys are defined as: 'an on-site inspection and evaluation […] of all conditions, devices, and practices in the water-supply system that pose an actual or potential danger to the health and well-being of the consumer' (WHO 1997). Sanitary surveys have been developed by the WHO for various water source types and are comprised of a simple checklist of components from the water source through the distribution channels where hazards may be present. The hazards are then quantified through a 'yes/no' risk checklist, with scoring based on the total number of questions to which the answer was 'yes'. For example on an 11 question report, 11 = very high risk and 1 = low risk (Figure 1).

Sample collection

Microbiological samples were collected directly from water sources in sterile 100-mL polystyrene vessels. Tubewells and

II	Specific diagnostic information for assessment	Risk
1.	Is there a latrine within 10 m of the well?	Y/N
2.	Is the nearest latrine on higher ground than the well?	Y/N
3.	Is there any other source of pollution (e.g. animal excreta, rubbish) within 10 m of the well?	Y/N
4.	Is the drainage poor, causing stagnant water within 2 m of the well?	Y/N
5.	Is there a faulty drainage channel? Is it broken, permitting ponding?	Y/N
6.	Is the wall (parapet) around the well inadequate, allowing surface water to enter the well?	Y/N
7.	Is the concrete floor less than 1 m wide around the well?	Y/N
8.	Are the walls of the well inadequately sealed at any point for 3 m below ground?	Y/N
9.	Are there any cracks in the concrete floor around the well which could permit water to enter the well?	Y/N
10.	Are the rope and bucket left in such a position that they may become contaminated?	Y/N
11.	Does the installation require fencing?	Y/N
	Total score of risks	/11

Contamination risk score: 9–11 = very high; 6–8 = high; 3–5 = intermediate; 0–2 = low

Figure 1 | WHO sanitary survey template for an open dug well (WHO 1997).

boreholes were pumped for at least 30 s before the sample was collected. Similarly, taps were allowed to run prior to sampling. The samples were stored in coolers containing ice packs; they were processed within eight hours according to Quanti-Tray® and QA/QC procedure (IDEXX 2010b). Samples were incubated at 35 °C for 24 h. For supplies tested for chlorine residual, taps were run for one minute prior to obtaining the sample, and analyzed according to Hach® standard procedure (Hach 2009).

Table 3 | Microbiological risk level corresponding to *E. coli* in sample. (Adapted from WHO (1997) by changing thermotolerant coliform to *E. coli*)

Risk level	*E. coli* in sample (CFU/100 mL)
Conformity	<1
Low	1–10
Intermediate	11–100
High	101–1,000
Very high	>1,000

RESULTS AND DISCUSSION

Water quality standards

Microbiological standards

The first Philippines water quality standards were published in 1993 and the most recent version of the Philippines National Standards for Drinking Water (PNSDW) was published in 2007 by the National Department of Health (DOH 2007).

The PNSDW states that, using standard methods of analysis (DOH 2007):

- Total coliforms should be at a conformity risk level (<1 colony-forming unit (CFU)/100 mL) for 95% of samples taken in a given time period (defined based on sample location).
- *Escherichia coli* test must give a result of <1.1 MPN/100 mL.

The WHO has developed risk levels for categorizing *E. coli* contamination within their Drinking Water Quality Guidelines (Table 3).

The results from the Quanti-Tray® are framed according to these risk levels. The type of Quanti-Tray® system used in Capiz Province only allows detection up to 200.5 CFU/100 mL; thus, the risk for the water quality test results are defined as Conformity, Low, Intermediate or High/Very High.

Chlorine residual standards

According to the WHO, after at least 30 min of contact time: 'the minimum residual concentration of free chlorine at the point of use should be 0.2 mg/L' (WHO 2004). The Philippines DOH requires free chlorine residual concentrations for Level 3 water supplies to ensure that the water remains disinfected. According to the Department of Health (DOH 1995), the free chlorine residual at any point that reaches the consumer as well as the any point in the distribution system must be between 0.2 and 0.5 mg/L.

Microbiological test results

A total of 563 water samples were collected and analyzed over the December 2009–March 2010 test period, as reported here, with subsequent testing occurring after that period up to 1,000 samples. The majority of samples were from Doubtful and Level 1 sources due to the stratified sampling design.

Results by source category

The risk levels are presented by source category and by cumulative percentage (Figure 2). The exact sample number per water source category is also included.

The figure shows a decreasing trend in High/Very High risk from Doubtful through to Level 3 source categories. Of the 55 Doubtful water sources sampled, 69% were categorized as Intermediate and High/Very High risk; in comparison, only 11% of Level 3 sources were of Intermediate risk and none of the 70 samples collected were of High/Very High risk. Similarly, an increasing trend in Conformity (i.e. free of fecal contamination) was seen from Doubtful to Level 3 sources. These Level 3 sources were generally municipal piped systems, which employed sand filtration and/or chlorination prior to distribution.

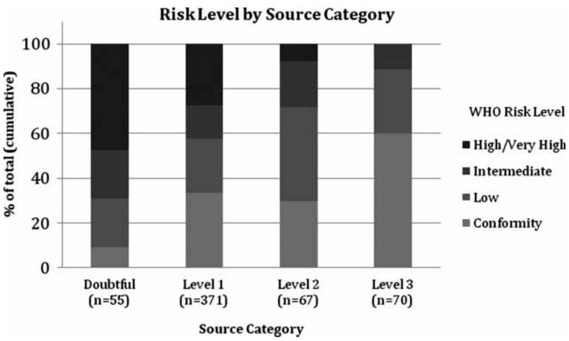

Figure 2 | Microbiological risk level by water source category (%).

Results by source type

In addition, water quality results are grouped according to specific water source types within each water source category; this was performed in order to determine if there were water quality trends by source type. The sample size for each water source type is an important consideration in the interpretation of these results (Figure 3).

Figure 3 shows that of the Doubtful or 'unimproved' sources (D), 78% of the open dug wells tested were at Intermediate or High/Very High risk. Fifty percent of unprotected spring sources were at Intermediate or High/Very High risk. This high proportion of contaminated samples is perhaps unsurprising for these 'unimproved' sources; however, it is of note that spring sources had higher water quality than dug wells in the sources sampled in Capiz Province. For Level 1 sources, which were 65% of the total water quality test program samples, the percentage of sources with Intermediate or High/Very High risk decreased from protected dug wells, deep well pumps, protected springs to Jetmatic pumps, with 67, 62, 43 and 42%, respectively. It is important to note that at least 40% of each of these 'improved' water source types had significant levels of fecal contamination (>10 CFU/100 mL). Of the Level 1 sources tested, rainwater sources showed the highest percentage of Low and Conformity risk samples (69%).

Level 2 and Level 3 source types all showed 70% or more of samples at Conformity to Low risk. These results indicate a decreased likelihood of contamination in water source types that have piped distribution or in systems that receive treatment prior to distribution. It also underscores the potential health benefits of increasing the proportion of the Capiz population with access to these services.

Chlorine residual results

Figure 4 shows the results of the 85 free chlorine residual tests completed in January 2010.

The figure shows two horizontal lines at the 0.2 and 0.5 mg/L chlorine residual concentration levels showing the WHO/DOH minimum level and DOH maximum level for

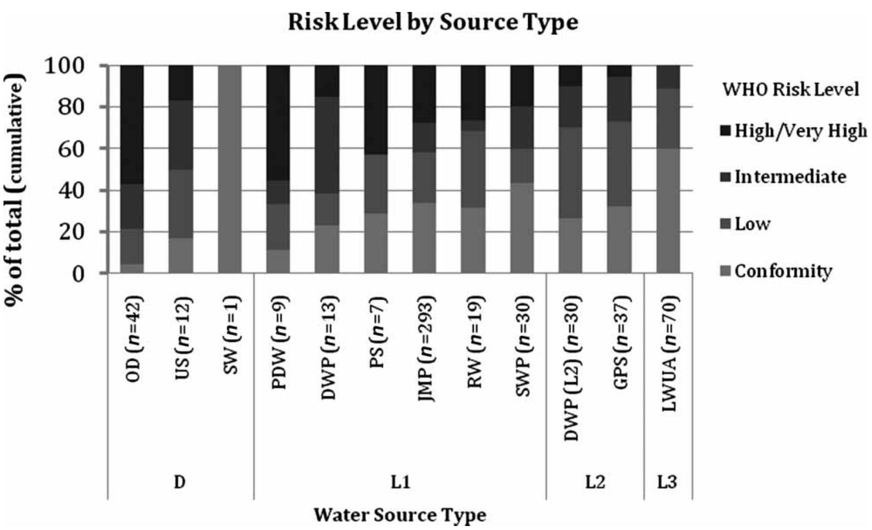

Figure 3 | Microbiological risk level by water source type (%). OD: open dug well; US: unprotected spring; SW: surface water; PDW: protected dug well; DWP: deep well pump; PS: protected spring; JMP: Jetmatic pump; RW: rainwater source; SWP: shallow well pump; DWP (L2): Level 2 deep well pump; GPS: gravity protected spring; LWUA: local water utilities administration.

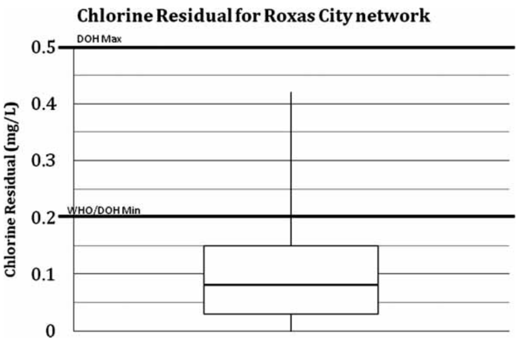

Figure 4 | Free chlorine residual for Roxas City, Panitan, Ivisan and Panay. WHO: World Health Organization; DOH: Department of Health (Philippines).

chlorine residual after 30 min of contact time, at any point in the distribution system. Only 17.6% of the samples met the WHO and DOH standards; the median was 0.08 mg/L.

Sanitary survey results

A total of 52 sanitary surveys were conducted in 13 municipalities during fieldwork in January 2010. Table 4 shows the risk according to the sanitary survey by percentage.

Table 4 shows that 77% of the sanitary surveys resulted in sources categorized as High/Very High risk according to the survey risk levels. The sanitary surveys revealed a number of hazardous activities taking place around water sources. The hazards varied per source type; however, the lack of site protection from access by animals was noted in almost every site survey. Additionally, the proximity of septic tanks, lack of drainage channels (enabling pooled water), and animal waste were found to be consistent hazards. The major infrastructure faults identified were damaged concrete platforms, lack of drainage channels, loose entry points, and faulty pumps.

Table 4 | Sanitary survey risk level of sources surveyed (%)

Risk level	Percent of sources surveyed (%)
Low	2
Intermediate	21
High	54
Very high	23

Importance of both sanitary surveys and microbiological water quality testing

While it has been previously underscored that drinking water quality testing and sanitary surveys are interdependent and complementary, concurrent use of the two is not consistently applied in drinking water quality programs in developing countries. Microbiological water quality is highly variable; a single test only represents a snapshot of the system in time. For example, a water sample could be free of fecal contamination on a given day, but the risk of contamination could still be very high due to faulty infrastructure and sanitation facilities in close proximity to the source. Therefore, in resource-limited settings where the frequency of testing is low, it is not possible to determine the actual safety of water sources solely from a water quality test result. Combining the results from both activities allows creation of risk level matrices which can then be used to prioritize actions to improve water safety (Lloyd & Bartram 1991; WHO 2004). Figure 5 illustrates this matrix for the 52 sources in Capiz Province on which both sanitary surveys and microbiological tests were conducted.

		Sanitary Survey											
	Risk	Low			Intermediate			High			Very High		
	Score	0	1	2	3	4	5	6	7	8	9	10	11
Water Quality Risk Results	High+ Very High			JMPx1		JMPx1	JMPx1 ODx1 PDWx1	JMPx1 ODx4	JMPx1	JMPx3	ODx4	ODx3	
	Intermediate						JMPx1	JMPx1	JMPx1 ODx2	JMPx1 ODx2	ODx2		
	Low				PSx1	JMPx2 ODx1 DWPx1		JMPx1 PDWx1	JMPx2 ODx2		ODx1		
	Conformity						PSx1	JMPx2	JMPx2	JMPx2	JMPx2		
Recommended Remedial Action		No Action	Low Risk: low action Priority			Intermediate to High Risk: higher action priority			Very High Risk: urgent action				

Figure 5 | Matrix integrating sanitary survey and microbiological water quality results. JWP: Jetmatic pump; OD: open dug well; PDW: protected dug well; PS: protected spring; DWP: deep well pump.

The combined approach shows that 77% of these 52 sources were at High risk, whereas water quality results alone indicated that only 40% of these sources were at High risk due to detected fecal contamination (Table 5).

Thus, for these sources in Capiz, conducting both these activities allowed a more conservative estimation of risk and by extension the actual safety of the water sources. This is in agreement with previous studies, which support the complementarity of these activities (Lloyd & Bartram 1991; Howard et al. 2003; Giannoulis et al. 2005).

Recommendations for at-risk supplies in Capiz Province

The recommendations for Capiz Province are based on the identification of at-risk supplies and are intended for implementation in the short to medium term. The long-term goal, however, must be to increase access to adequately treated, piped supplies of drinking water. Additionally, the development of WSPs should be a central part of the long-term strategy (Bartram et al. 2009).

Additional water quality sampling: microbiological tests

Given the importance of microbiological data to assess drinking water sources, it is recommended that the PHO pursue resources to conduct representative drinking water quality programs in Capiz Province. Additionally, regulatory documents in the Philippines provide guidelines for the recommended water quality sampling frequency. For microbiological testing, The Philippines National Standards for Drinking Water (2007) states that the minimum frequencies for sampling public drinking water supply systems are as shown in Table 6 (DOH 2007).

Table 5 | Risk level of sources surveyed ($n = 52$) according to water quality results only and combined water quality results and sanitary surveys

Risk level	Water quality (%)	Combined results (%)
Conformity (no action)	17	0
Low (low priority)	23	2
Intermediate (higher priority)	19	21
High/very high (urgent action)	40	77

Table 6 | From Philippines National Standards for Drinking Water (2007)

Source and mode of supply	Population served	Minimum frequency of sampling
a. Level 1	90–150	Once in 3 months
b. Level 2	600	Once in 2 months
c. Level 3	Less than 5,000	1 sample monthly
	5,000–100,000	1 sample per 5,000 population monthly
	More than 100,000	20 samples and additional 1 sample per 10,000 population monthly

This recommended sampling frequency will be a longer-term goal as funds for microbiological testing increase. In the short term, biannual sampling is recommended as this is especially important in locations with distinct wet and dry seasons. Continued research on the efficacy of field-based tests and subsequent promotion of accurate, low-cost methods will contribute to enabling the required frequency of sampling in Capiz Province and other developing areas alike.

Additional water quality sampling: chlorine residual tests

The 85 samples tested for chlorine residual in Roxas City, Panay, Panitan and Ivisan showed poor compliance with the DOH's mandated range for free chlorine residual in the network. The network's map should be matched with results, and additional testing should be conducted at the treatment plants and at known locations throughout the network to decide on an effective chlorine dosing system. Furthermore, given the scale of the Roxas City water treatment system, this should be prioritized for the development of a comprehensive WSP in the immediate future.

Household water treatment and safe storage

While Capiz is building technical and financial capacity to improve the safety of existing water sources and to increase access to piped/treated drinking water supplies, an interim recommendation is to increase access to household water treatment and safe storage (HWTS). Moreover, these options are often useful for providing an additional barrier of protection against microbial contamination (Fewtrell & Colford 2005; Sobsey *et al.* 2008). There are a variety of HWTS options available in the Philippines, which should be explored by the PHO, such as biosand filters, Aquatabs, PuR®, Megafresh™ filters, and ceramic pot filters.

Regular sanitary surveys

The results from the sanitary surveys reveal infrastructure faults and lack of site protection around water sources, which provide potential causal links to the microbial contamination found in many of the water sources. These identified hazards from lack of site protection could be reduced with education and regular monitoring. The WHO recommends that sanitary surveys be conducted six times per year for open dug wells and four times per year for protected dug wells, springs, and tubewells (WHO 1997). While water quality testing at these intervals might be limited by existing resources, sanitary surveys can be conducted in Capiz at present, without additional financial or technical resources. In Capiz, it is recommended that a municipal committee be created to enforce this at the local level, and in turn they could report to the province with the results from the surveys. These should be kept in a database, along with water quality test results, in order to prioritize remedial action. In the longer term, these activities should be incorporated into WSPs as they are implemented.

Improving management

In Capiz, municipal water utilities are well-positioned to assist local level efforts at management and organization. Information can be shared about resources for monitoring and inspection, and they can potentially help with setting up a system for database management and a schedule for monitoring. They might also be able to assist with acquisition of spare parts and provision of technical support in repairing/maintaining infrastructure. Case studies from elsewhere in the Philippines have demonstrated the potential for these larger, well-established, and better-funded organizations to act as advisors on technical and financial management systems (World Bank 2003, 2004).

Training technicians

There have been examples from around the world which have shown the potential for local citizens to be trained as water source technicians (Mudgal 1997; Mikelonis 2008; UNICEF 2009; WaterAID 2010). These successful programs in both Latin America and South Asia demonstrate how it is possible for local citizens to be trained as technicians to overcome deficits in access to funds and technical support from higher levels of government.

There is potential for interested citizens in Capiz to become involved in water management at a municipal scale. In every village visited during fieldwork in January 2010, there was at least one person with experience and technical know-how in repairing water supplies. Moreover, there were people who were willing to contribute to the upkeep and maintenance of supplies. If there was an opportunity for a person(s) to gain a paid position by the PHO to travel around a district and provide technical assistance for village water sources, this could enable significant improvements to the current water safety situation around the province. It is recommended that the PHO explores funding routes for creating these municipal-level positions, and concurrently seeks the technical advisors it would require to provide training for these technicians through the local water utility administration or water district.

CONCLUSIONS

The results of the drinking water quality test program and the limited results of the sanitary surveys completed during January 2010 in Capiz reveal both the challenges and the opportunities that exist with respect to drinking water quality and water management. While the sample design was skewed towards suspected contaminated sources, the large proportion of sources sampled with *E. coli* contamination has and will continue to serve as an important source of awareness about the need to focus on water safety.

E. coli test results showed that Doubtful and Level 1 sources had higher percentages of Intermediate and High/

Very High risk. Even though Level 1 sources are defined as 'improved', the majority of these sources tested in Capiz Province had fecal contamination. Microbiological water quality increased within Level 2 and Level 3 water source types. Thus, the results from this preliminary sampling program indicate that efforts should be focused towards developing water supplies that are ideally treated and at least piped to access areas. However, of the treated drinking water samples which were tested only for chlorine residual, most did not meet the WHO/DOH minimum chlorine residual requirements; therefore, it is necessary to continue to build technical capacity within these operations to ensure the safety of these supplies.

The sanitary surveys generally showed that many hazards are present in close proximity to water sources, and that it is highly likely that some of these – specifically septic tanks and animal waste – are contributing significantly to poor water quality. Combining these results with water quality results in a matrix allowed a more conservative estimation of the risk than by the water quality results alone. These results reinforce the importance of concurrently conducting these activities in resource-limited settings, to determine the actual safety of water sources and to prioritize remedial actions. The complementarity of these activities is in agreement with previous studies.

The next steps are for the PHO to conduct representative water quality testing (both microbiological and chlorine residual) and sanitary surveys. It is also recommended that the PHO explores the potential use of HWTS in the short term, given the large number of contaminated sources. Training local citizens to act as technicians to repair, inspect and maintain existing infrastructure is critical for preventing continued contamination of water sources. Longer-term plans need to include the development of effective management systems both at the municipal and provincial level, in which WSPs should be a central component.

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