An examination of microbiological water quality in Kigoma, Tanzania using a test for the presence of H_2S-producing bacteria

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Introduction

The transmission of disease caused by pathogenic microorganisms in drinking water represents a health risk in all societies. Therefore, unpolluted safe drinking water is usually considered one of the primary requisites for healthy human life (Pillai et al., 1999). However, in developing countries, there is often a lack of resources to reliably test the performance of water treatment and distribution systems. In response to this need, a simple test developed by Manja et al., (1982) detects potentially pathogenic microorganisms in water by using hydrogen sulfide (H_2S) producing bacteria as indicators.

The H_2S-producing bacteria have been shown to be present when the traditional indicator bacteria, total coliform bacteria and fecal coliform bacteria, are present (Pillai et al., 1999; Grant and Ziel, 1996; Kaspar et al., 1992; Kromoredjo and Fujioka, 1991). Also, this test is recommended as one of several tests used to evaluate drinking water quality in tropical countries (Martins et al., 1997; Kromoredjo and Fujioka, 1991). The test for H_2S-producing bacteria is inexpensive, easy to operate, and reagents can be prepared locally and don't need to be refrigerated. In addition, this test can be incubated at ambient temperatures in the tropics. Pillai et al. (1999) found that this test could detect bacteria at a temperature range of 20-40^{o}C, and the temperature need not be constant. Thus, developing countries may find this test more appealing than the membrane filtration test or multiple tube fermentation tests recommended in Standard Methods for Water and Wastewater Treatment.

The city of Kigoma, Tanzania has a population of 135,000 and is situated in western Tanzania on the shore of Lake Tanganyika. The drinking water source for most of the city is lake water distributed by the city's water system. Many residents complain of water outages, poor quality water, and also heavily chlorinated water. The fear of consuming contaminated water has lead to the widespread practice of boiling and/or filtering tap water before drinking or the consumption of bottled water. These practices add a significant cost to consumers, produce extra pressure on scarce wood resources, and disposal of plastic water bottles is potentially problematic. In addition, the presence of endemic diseases and outbreaks like diarrhoea, dysentery, giardia, cholera, and typhoid suggests the contamination of drinking water and extract a heavy toll on the residents both mentally and physically.

This study examined the microbiological water quality, using the presence of H_2S-producing bacteria as indicator organisms, of 15 water samples from Lake Tanganyika and 27 water taps in Kigoma, Tanzania. These results were compared to 4 water samples from the outlet of the water holding tanks where treatment, disinfection by chlorine, occurs. The amount of residual chlorine and the presence/absence of the indicator organisms in the water samples were used to evaluate the effectiveness of this treatment.

Kigoma Water Supply and Distribution System

In Kigoma Bay, south of Luanza Point and north of Bangwe Point (see Figure 1) the city operates a water intake system consisting of five water intake pipes and several pumps. The pipes extend about 10 m from the shoreline in approximately 2 m of water.

In the study area there are several residences, the TANESCO electrical generation facility (diesel generators), hotels, offices, police barracks, and a jail. In the past five years there have been observations of diesel oil discharges in this area of the lake. It appears that this source of contamination has been reduced significantly due to remedial actions taken by TANESCO. Other observations made in this area include the failure of the police barracks' and jail's wastewater disposal system. It is unknown how other residences and businesses dispose of their wastewater. Depending on the season (rainy season, dry season, and wind conditions) contamination from other sources may enter the area of the water intake.

The pumps at the water intake facility pump lake water about 74 m above the lake surface to two concrete holding tanks with a combined volume of 772 m^3 (these are the mid-level tanks, one tank is referred to as the new tank, and one tank is called the old tank). There is one wet well at the intake facility and water is pumped from this location in addition to five pipes that pump water directly from the lake. The amount of water pumped from the lake is about 15,000 m^3/day. At the holding tanks chlorine is added in a dilute solution (5%) to disinfect the water. The disinfection process is not automated and depends on operators to control the rate according to regular testing (hourly) conducted at the outlet. The World Health Organization guideline of 0.2 - 0.5 mg/l residual chlorine is the standard used to regulate chlorine input. Disinfection by chlorination is the only method of water treatment for the public water supply in Kigoma.

Some water from both mid-level holding tanks is mixed and flows by gravity to low lying areas of Kigoma (i.e. Kigoma City, Kibirizi, and Bangwe). In addition, some water bypasses the mid-level tanks and is pumped by booster pumps (at the mid-level tank location) to one concrete tank which has a volume similar to one of the mid-level tanks (this tank is called the high-level tank). The high-level tank is about 40 m in elevation above the mid-level tanks. The water is disinfected in a similar fashion to the mid-level tanks. This water flows by gravity to high-elevation regions of Kigoma. Some water from one of the mid-level tanks (old tank) is also pumped, 91 m in elevation, by booster pumps to another holding tank in a different area (this tank is called the Vamia tank). Water from the Vamia tank serves the highest elevation locations and most remote locations in the distribution system (i.e. Ujiji).

Methods

Water samples were taken between 19 July 2002 and 2 August 2002 from 27 water taps in the Kigoma distribution system: at the outlets of three water storage tanks (mid-level and high-level); in the bay near the intake to the water intake facility; in the lake at "pristine" locations; and in the lake at offshore locations. The 27 samples from water taps came from all 5 of the water pressure distribution zones of Kigoma (see Figure 1). The sample sites (water taps) were chosen based first on their use (i.e. water kiosks and distribution points were favored because these locations are heavily used). Other sites were chosen because of their remoteness from the water holding tanks (i.e. Ujiji and Kibirizi). Some sites were chosen because of their proximity to heavily settled areas (i.e. Mwanga and Kigoma City). Lastly, some sites were chosen for their accessibility, (i.e. Lake Tanganyika Beach Hotel and TAFIRI). If water was not available at the time of sampling, the tap was visited again subsequently when water was available.

For samples from water taps, Hach's pathoscreen medium was placed in sterilized glass or plastic sample bottles at the site and 100 ml of sample were added. The cap of the bottle was tightly screwed and the sample mixed completely. Samples collected from the lake were immediately placed on ice and added to the Hach pathoscreen medium within 5 hours. The samples were stored at ambient temperature (23-28^{o}C during the study period). After 24 hours, 48 hours, and 72 hours the samples were analyzed for a color change to black. Samples with color changes or black precipitates within 72 hours indicated the presence of H_2S-producing bacteria. According to Kaspar et al. (1992), the reaction of iron ions with H_2S causes a color change from yellow to black.

For most probable number (MPN) testing of lake samples, 5 test tubes containing 20 ml of diluted (10x) lake water were incubated at ambient temperature (according to Hach MPN testing procedure). The number of positive test tubes has a corresponding most probable number of bacteria in the sample. At the time of the sampling, the pH was measured by an electronic pH electrode, and residual chlorine was measured at water taps and the water storage tanks using a simple colorimetric detector similar to the type used for swimming pools.

Sampling bottles and pipettes were sterilized using a pressure cooker for 15 minutes at about 110^{o}C. In addition, a sample of deionized water was tested for the presence of H_2S-producing bacteria in order to evaluate the methodology.

Results

Sampling results for water taps, lake samples, and the water storage tanks are not included, but all samples from water taps that tested positive for H_2S-producing bacteria, are shown as triangles in Figure 1. The results for the water taps are grouped according to their water pressure zone and shown in the table below. This table shows the number of samples from each zone, the average residual chlorine concentration, the number of positive samples for H_2S-producing bacteria, and the percentage of positive samples. It can be seen that all samples from Kigoma/City were negative. Thus, Kigoma/City was compared to all other zones, and this information is shown in Figure 2. This figure shows that 52% of the water samples from taps in all zones except Kigoma/City were positive.

Table 1: Presence of H2S-Producing Bacteria in Water Tap Samples

Pressure Zone	Number of Samples	Average Residual Chlorine	Number of Positive Samples	% Positive
Kigoma/City	6	0.17	0	0
Kigoma/other	5	0.06	2	40
Mwanga	7	0.18	5	71
Gungu	2	0	2	100
Majengo	4	0.08	2	50
Ujiji	3	0.35	0	0
Total	**27**	**0.15**	**11**	**41**

Seventy seven percent (77%) of water tap samples tested positive when the residual chlorine was <0.1 ppm (Figure 3a). In contrast, 7% of water tap samples tested positive when the residual chlorine was greater than or equal to 0.1 ppm (Figure 3b).

Most lake samples (8/9) in the area between Luanza Point and Bangwe Point were found positive for H_2S-producing bacteria, and the highest MPN (26 per 100 ml) in this area were near the water intake and 200 m out from the intake. Half of the lake samples (2/4) in areas considered "pristine" were positive for H_2S-producing bacteria. No positive samples were observed in the 2 offshore samples.

Both samples at the new tank were found positive, at residual chlorine 0.2 ppm on 19 July and at residual chlorine 0.7 on 1 August. The samples at the old tank and high-level tank were negative.

Discussion

Eight of nine samples in the bay encompassing the water intake were positive for H_2S-producing bacteria. This area was likely to contain these bacteria because of the influence of domestic wastewater. However, two samples at remote beaches (considered "pristine") indicates that the presence of H_2S-producing bacteria may be from naturally occurring bacteria, not of fecal origin, and introduces the possibility of false positives. Pillai et al. (1999) suggest these bacteria are due to non-*Enterobacteriacea* such as *Clostridium perfringens*, although other studies (Martins et al., 1997; Castillo et al., 1994) have shown a close correlation between the *Clostridium* species and various pathogenic bacteria. In addition, fecal coliforms have been found at beaches north and south of Kigoma (Steendam, personal communication). It is recommended in future studies that the bacteria found in positive samples be isolated to establish their potential as human pathogens.

Since the new tank tested positive for H_2S-producing bacteria, one conclusion is that the disinfection process in that tank is not effective. Either the dose and contact time may be inadequate (since positive results were observed at both 0.2 ppm and 0.7 ppm residual chlorine), or these bacteria are resistant to chlorine. The later is unlikely since the old tank and high-level tank both tested negative, at residual chlorine values of 0.7 ppm and 0.9 ppm respectively.

The water in the taps that tested positive may be due to the naturally occurring bacteria in the lake that escaped disinfection and may pose no risk to the public. However, as mentioned previously, these bacteria in the lake may be pathogenic. Another possibility is that these bacteria are entering (or regrowing in) the distribution system after the lake water has been disinfected. This study was unable to differentiate where the bacteria entered the system. Bacteria entering the distribution system are particularly problematic and certainly realistic, as explained below.

A common complaint from users of the Kigoma water system is the numerous water outages. In addition to being a serious inconvenience this is also a major means for contamination to enter the water distribution system. During the period when water is not flowing in the distribution system, the pressure inside the pipes is the same or even lower that the surrounding environment (negative pressure). This allows untreated groundwater and wastewater to enter the pipes. The residual chlorine in the pipes cannot be expected to treat this water since the demand for chlorine would be excessive.
It appears that residual chlorine is very important in maintaining water quality in the Kigoma water distribution system since 77% of samples with < 0.1 ppm residual chlorine showed positive for H_2S-producing bacteria, and only 7% of samples with 0.1 ppm or greater residual chlorine were positive. These results agree with other studies in tropical countries (Martins et al., 1997) and underscore the importance of disinfection for the Kigoma water supply and distribution system.

There is no significant difference in residual chlorine values between Kigoma/City Zone and the remaining zones, but there is a large difference in positive samples (all 6 samples were negative in Kigoma/City Zone and 10/21 samples were positive in the remaining zones). This may be explained by water availability. It appears that water is almost always available in Kigoma/City, but the other zones are subject to frequent water outages (personal observation). As explained above, this is an opportunity for contamination to enter the system. An additional study correlating water availability and presence of bacteria would be useful.

The H_2S-producing bacteria test is appropriate, it is easier to use and is cheaper than the procedures recommended in Standard Methods. Also, it eliminates the need for incubation at high temperatures. However, it is recommended that it be used in conjunction with procedures like membrane filtration and multiple tube fermentation because these are the observed standards for water quality analysis. In addition, the H_2S-producing bacteria test is appropriate for monitoring drinking water quality in remote locations, as a screening test for drinking water systems (Nair et al., 2001), and in emergency situations when large amounts of water need to be tested.

An additional study of the water quality in Kigoma during the rainy season would be beneficial, since it is during this time that rain facilitates the transport of contamination (agricultural, industrial, and human) into the lake. Also, a survey of water usage and health data for typical water-borne diseases in Kigoma is important. These studies could distinguish if the causes of diseases are in fact from the Kigoma water supply system or from contaminated food and wells, vectors, or poor hygiene. Also, the benefits derived from any improvements made to the water supply system could be estimated.

Potential remedies to improve the quality of the drinking water in Kigoma are as follows:

- Decrease the number of pipes and taps in the region in order to have consistent water pressure. This would create hardships for many residents and is not an acceptable solution. In addition, the use of buckets and storage vessels is a major means of introducing contamination (Roberts, from his study in Malawi refugee camps).
- Build additional water storage tanks and increase the pumping capacity of the pumps. This solution is expensive and may not be obtainable without outside assistance.

Regardless of any other solutions, the automation of the disinfection process is important to obtain consistent chlorination. This may include designating one tank as disinfection only and not water supply, so that the appropriate volume of water is always in the tank and the contact time for chlorine is sufficient. Minimally, the chlorine mixing basins should be enclosed and protected.

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Standard Methods for Water and Wastewater Treatment.

Table 1. Sampling Results for Residual Chlorine and Presence of H_2S-Producing Bacteria (Tap Samples)

Sample	Description	Pressure Zone	Sample Date	pH	Residual Chlorine (ppm)	H_2S-Producing Bacteria Presence/Absence			Fe mg/L	NH_3 mg/L	Hardness mg/L
						24 hours	48 hours	72 hours			
1	water office	Ujiji	19-Jul	8.70	0.6	A	A	A	0.05	-0.01	-
6	Tafiri	Kigoma City	20-Jul	8.86	0.3	A	A	A	0.08	-0.01	-
7	L. Tang. Beach Hotel	Kigoma City	20-Jul	8.82	0.1	A	A	A	0.06	-0.01	-
10	**Buteko**	**Kigoma**	22-Jul	8.81	**0.1**	**P**	**P**	**P**	-	-	-
11	Katonga	Kigoma	22-Jul	8.84	0.1	A	A	A	0.08	-0.01	-
12	Roundabout	Kigoma City	22-Jul	8.82	0.1 - 0.3	A	A	A	0.07	-0.01	-
13	**Kibirizi**	**Kigoma/Kibirizi**	22-Jul	8.76	**<0.1**	**P**	**P**	**P**	0.06	0.02	-
14	Livingstone Memorial	Ujiji	23-Jul	8.81	<0.1	A	A	A	0.08	0.00	-
15	Ujiji Primary School	Ujiji	23-Jul	8.82	0.3 - 0.6	A	A	A	0.08	0.00	-
16	**Mlole Church**	**Mwanga**	23-Jul	8.75	**<0.1**	**P**	**P**	**P**	0.10	0.00	-
17	Mwanga (Kitambwe)	Mwanga	23-Jul	8.81	0.6 - 1.0	A	A	A	0.13	0.00	-
18	Mwanga Kiosk	Mwanga	23-Jul	8.84	0.3 - 0.6	A	A	A	0.15	0.00	-
23	Majengo	Majengo	26-Jul	8.75	0.1	A	A	A	-	-	253
24	Mlole Masango (Maji office)	Majengo	26-Jul	8.85	0.1 - 0.3	A	A	A	-	-	200
25	Kigoma (house on Lumumba)	Kigoma City	26-Jul	8.75	0.3	A	A	A	-	-	203
26	Kibirizi (Ustawi wa Jamii)	Kigoma/Kibirizi	27-Jul	8.82	0.1	A	A	A	-	-	209
27	Kibirizi (near town)	Kigoma/Kibirizi	27-Jul	8.76	<0.1	A	A	A	-	-	206
28	Diplomatic Village	Kigoma City	27-Jul	8.82	<0.1	A	A	A	-	-	204
32	**Gungu #1 (private house)**	**Gungu**	29-Jul	8.79	**<0.1**	**P**	**P**	**P**	-	-	
33	**Gungu #2 (private house)**	**Gungu**	29-Jul	8.79	**<0.1**	A	**P**	**P**	-	-	
34	Kigoma (private house near UNHCR)	Kigoma City	29-Jul	8.82	0.1	A	A	A	-	-	
36	**Maweni (near hospital)**	**Mwanga**	1-Aug	8.80	**<0.1**	**P**	**P**	**P**	-	-	
37	**Kilimahewa (private house - not from tap)**	**Mwanga**	1-Aug	8.77	**<0.1**	**P**	**P**	**P**	-	-	
38	**Katubuka (private house)**	**Majengo**	1-Aug	8.78	**<0.1**	**P**	**P**	**P**	-	-	
39	**Katubuka (hoteli)**	**Majengo**	1-Aug	8.77	**<0.1**	**P**	**P**	**P**	-	-	
41	**Mwanga Mjini (private house)**	**Mwanga**	2-Aug	8.75	**<0.1**	A	**P**	**P**			
42	**Mwanga Market (duka)**	**Mwanga**	2-Aug	8.77	**<0.1**	**P**	**P**	**P**			
29	Distilled Water	-	27-Jul	-	-	A	A	A	-	-	-

P=Present, A=Absent

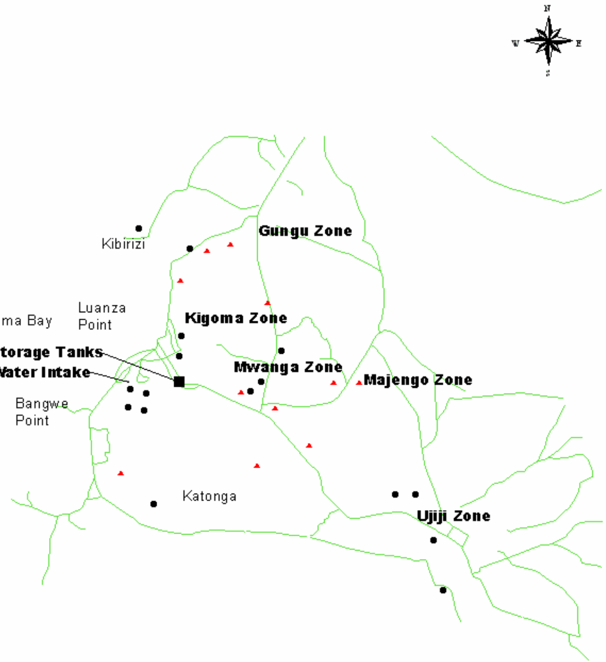

Figure 1. Sampling Locations for Water Taps

• **Samples negative for H2S producing bacteria**

▲ **Samples positive for H2S producing bacteria**

Table 2. Sampling Results for Presence of H_2S-Producing Bacteria (Lake Samples)

Sample	Description	Location	Sample Date	pH	Residual Chlorine (ppm)	H_2S-Producing Bacteria Presence/Absence			Fe mg/L	NH_3 mg/L	Hardness mg/L
						24 hours	48 hours	72 hours			
5	**intake (sump-well)**	**nearshore**	19-Jul	8.79	-	A	**P**	**P**	0.06	-0.01	-
8	**prison**	**nearshore**	20-Jul	8.83	-	**P**	**P**	**P**	0.08	0.05	-
9	**Aqua Lodge**	**nearshore**	20-Jul	8.86	-	A	**P**	**P**	0.06	0.00	-
19	Jacobson's Beach	nearshore/pristine	25-Jul	8.85	-	A	A	A	0.06	0.00	-
20	Jacobson's Beach (north)	nearshore/pristine	25-Jul	8.83	-	A	A	A	0.06	0.01	-
21	**Jacobson's Beach (south)**	**nearshore/pristine**	25-Jul	8.86	-	A	**P**	**P**	0.10	0.00	-
22	**Zungu Beach**	**nearshore/pristine**	25-Jul	-	-	A	**P**	**P**	-	-	-
30	200 m out from Bangwe Point	offshore	27-Jul	8.82	-	A	A	A	-	-	220
31	end of bay	offshore	27-Jul	8.85	-	A	A	A	-	-	-
35	**Lake Tang. Beach Hotel**	**nearshore**	29-Jul	8.84	-	**P**	**P**	**P**	-	-	-
MPN-1	**prison**	**nearshore**	31-Jul	8.83	-		**MPN=11/100 ml**				
MPN-2	**Hilltop Beach**	**nearshore**	31-Jul	8.79	-		**MPN=11/100 ml**				
MPN-3	**200 m from intake**	**nearshore**	31-Jul	8.80	-		**MPN=26/100 ml**				
MPN-4	**near intake**	**nearshore**	31-Jul	8.78	-		**MPN=26/100 ml**				
MPN-5	Aqua Lodge	nearshore	31-Jul	8.77	-		MPN<11/100 ml				

P=Present, A=Absent

Table 3. Sampling Results for Residual Chlorine and Presence of H_2S-Producing Bacteria (Storage Tank Samples)

Sample	Description	Sample Date	pH	Residual Chlorine (ppm)	H_2S-Producing Bacteria Presence/Absence			Fe mg/L	NH_3 mg/L	Hardness mg/L
					24 hours	48 hours	72 hours			
2	**new tank (mid-level)**	19-Jul	8.72	**0.2**	**P**	**P**	**P**	0.07	0.01	-
3	old tank (mid-level)	19-Jul	8.82	0.7	A	A	A	0.10	0.18	-
4	high-level tank	19-Jul	8.83	0.8	A	A	A	0.06	0.08	-
40	**new tank (mid-level)**	1-Aug	-	**0.6 - 0.8**	**P**	**P**	**P**	-	-	-

P=Present, A=Absent

Figure 3. Water Tap Samples (Comparison Between Kigoma/City Zone and Other Zones)

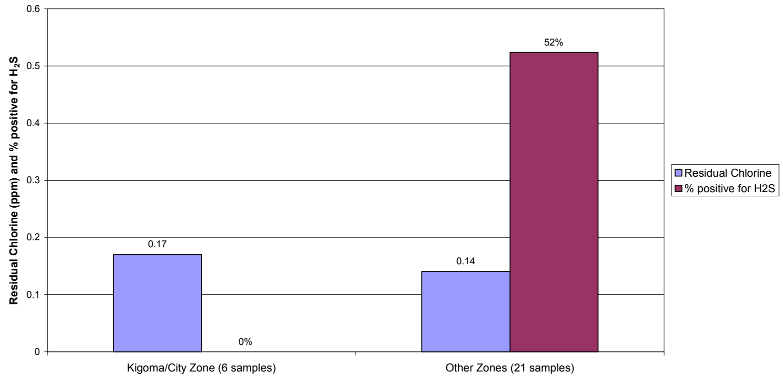

Table 3. Presence of H_2S-Producing Bacteria in Water Tap Samples (According to Pressure Zone)

Pressure Zone	Number of Samples	Avg. Residual Chlorine (ppm)	Number of Samples Positive for H_2S	% Positive
Kigoma/City	6	0.17	0	0%
Kigoma/other	5	0.06	2	40%
Mwanga	7	0.18	5	71%
Gungu	2	0	2	100%
Majengo	4	0.08	2	50%
Ujiji	3	0.35	0	0%
Total	27	0.15	11	41%

Table 4. Presence of H_2S-Producing Bacteria in Water Tap Samples (Kigoma/City Zone vs. Remaining Zones)

Pressure Zone	Number of Samples	Avg. Residual Chlorine (ppm)	Number of Samples Positive for H_2S	% Positive
Kigoma/City Zone (6 sam	6	0.17	0	0%
Other Zones (21 samples	21	0.14	11	52%

No. samples (Cl < 0.1)	Positive for H_2S	Negative for H2S
13	10	3

No. samples (Cl >= 0.1)	Positive for H_2S	Negative for H2S
14	1	13

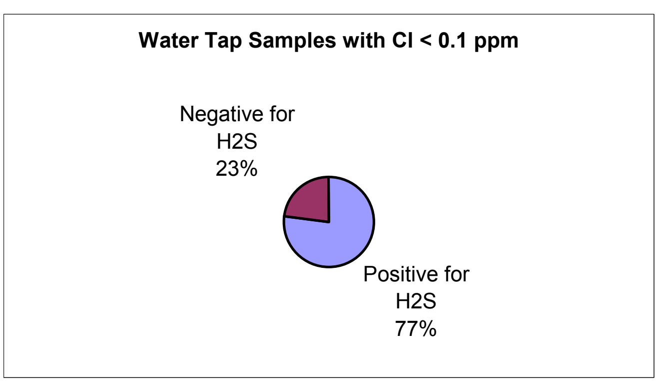

Figure 3a. Residual Chlorine and Presence of H_2S-Producing Bacteria Comparison (Cl < 0.1 ppm)

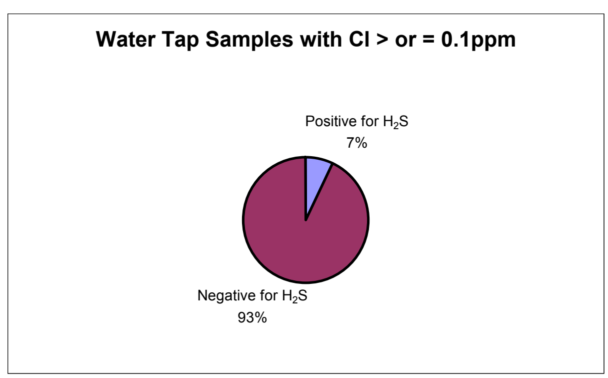

Figure 3b. Residual Chlorine and Presence of H_2S-Producing Bacteria Comparison (Cl > or = 0.1 ppm)