  Journal of Water and Health | 13.3 | 2015

Microbial and chemical safety of non-commercially packaged water stored for emergency use

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ABSTRACT

Water storage is one of the most important components of emergency preparedness. Potable water is needed for ensuring the survival and well-being of disaster victims. Consumers may store water in previously used beverage or other food-grade containers for emergency use; however, this practice poses potential safety risks. Water stored in various containers for emergency purposes in residences within the state of Utah was tested for various contaminants. Of 240 samples, seven contained coliforms and 14 samples had free chlorine levels over the Environmental Protection Agency (EPA) 4 parts per million limit. There was a negative correlation between chlorine levels and age of water. The probability that a container had free chlorine present decreased by 4% for each month of storage, suggesting the importance of preventing subsequent contamination of water during storage and use. Water in clear polyethylene terephthalate plastic soda bottles ($n = 16$), even when stored for >18 months, did not exceed 0.3 parts per billion (ppb) antimony, a level significantly lower than the EPA limit of 6.0 ppb antimony. These results support the practice of utilizing previously used containers, when properly cleaned and chlorinated, for emergency water storage.

Key words | antimony, chlorine, coliforms, plastic, water storage

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NOMENCLATURE

PET polyethylene terephthalate
ppm parts per million
ppb parts per billion
L liter
MCL maximum contaminant level
mL milliliter
°C degrees Celsius
UV ultraviolet
nm nanometer

INTRODUCTION

The World Health Organization (WHO) generates international water quality guidelines that are used in setting standards and regulations for water quality world-wide (WHO 2015). In the USA, the Safe Drinking Water Act passed in 1974 was established to ensure the safety and quality of drinking water and its sources (EPA 2011a). However, during a disaster, such as an earthquake or flood, disruptions in the water treatment system can leave residents without potable water. Water storage is one of the most important components of emergency preparedness; potable water is needed to ensure the survival of disaster victims (Lillibridge 1997).

Water storage for emergency preparedness purposes can be achieved through the purchase of water in commercial packages or by filling containers with tap water. The US Federal Emergency Management Agency (FEMA) recommends that consumers store commercially packaged water, but also provides instructions explaining how to prepare tap water for storage (FEMA 2010). The instructions suggest that tap water be stored in new food-grade water storage containers, available at camping supply stores, or in previously used polyethylene terephthalate (PET) plastic soft drink bottles. WHO recommends that water be stored in containers

doi: 10.2166/wh.2015.182

that are easy to clean, are durable and strong, have a narrow opening to prevent external contamination, have a stable base to prevent tipping, and have a lid that seals tightly (WHO 2013). FEMA discourages the use of plastic jugs and cardboard containers that have been used to store milk or fruit juice. The use of glass containers is also discouraged because they are heavy and can easily break. FEMA & American Red Cross (2004) recommend containers be cleaned thoroughly with dishwashing soap and water, and rinsed to remove any residual soap. The container should then be sanitized with a bleach solution (0.5%) and rinsed again with clean water before filling with tap water. If the water is not treated with chlorine, two drops of non-scented liquid chlorine bleach should be added to every 3.8 liters (L) (1 gallon). Other chlorination recommendations include adding 4 drops of household bleach per liter of clear water (WHO 2011), or adding one cap full of liquid chlorine bleach, using the cap on the bleach container, to clear water in a standard 10 L storage container (UNICEF 2008).

The practice of consumers filling their own containers for water storage poses potential safety risks (Sobsey *et al.* 2003; Graham & VanDerslice 2007; Wright *et al.* 2009). Safety concerns in stored drinking water include pathogenic micro-organisms and other contaminants. The presence of coliform bacteria in water can signify poor sanitation and the possibility of pathogenic bacteria. The test for total coliforms is often performed simultaneously with *Escherichia coli*. Although most *E. coli* strains are harmless, a few strains are pathogenic. The presence of such pathogenic *E. coli* would be of particular concern due to their ability to be transmitted via water (Edberg *et al.* 2000).

Chlorine can control pathogens and increase the safety of water when added at appropriate levels (Ashbolt 2004). Chlorine, typically chlorine bleach (sodium hypochlorite), should be added to water that will be stored only if it does not already contain chlorine, such as water from a private well (FEMA & American Red Cross 2004). Wright *et al.* (2009) tested samples of stored water in Cedar City, Utah, USA, for coliforms, *E. coli,* and chlorine, and indicated that excessive in-house chlorination may be a problem.

The Environmental Protection Agency (EPA) sets standards for public water systems that define the maximum contaminant level (MCL) for drinking water. The EPA standards are legally enforceable and can be found in the National Primary Drinking Water Regulations (EPA 2011b). In drinking water there are approximately 90 contaminants that have established standards. Although water may contain a variety of inorganic chemical contaminants, antimony is of particular concern for water stored in PET plastic bottles since it is used as a catalyst in making the bottles. Antimony leaches from PET plastics and may pose a health risk for consumers when it exceeds the EPA MCL of 6 parts per billion (ppb) (Shotyk *et al.* 2006; Shotyk & Krachler 2007; Westerhoff *et al.* 2008). Acute health effects include nausea, vomiting, diarrhea, and abdominal cramps. Chronic health effects include increased blood cholesterol and decreased blood sugar (WHO 2003; Westerhoff *et al.* 2008). Antimony leached from PET plastic has been shown to increase with the length of water storage (Shotyk & Krachler 2007). Westerhoff *et al.* (2008) found antimony levels exceeded EPA limits when water was stored at high temperatures mimicking summer conditions in Arizona, where a large amount of bottled water is consumed.

The purpose of this study was to evaluate the safety of non-commercially packaged water stored for various lengths of time by consumers throughout the state of Utah, by testing for coliforms, *E. coli,* free chlorine, and antimony.

METHODS

Water sample selection

Samples for total coliforms, *E. coli*, and chlorine testing were obtained from randomly selected Utah residents ($n = 1{,}412$) who completed an emergency preparedness survey conducted by the Utah State Department of Health. The emergency preparedness survey was a call-back survey contacting previous participants in the Behavioral Risk Factor Surveillance System (BRFSS) Survey (Ablah *et al.* 2009). The BRFSS is conducted annually by individual US state health departments and run by the Centers for Disease Control and Prevention. Using BRFSS participants allowed population differences to be accounted for when selecting Utah residents for the follow-up stored water survey reported herein.

Of these 1,412 Utah BRFSS participants who responded to the emergency preparedness survey, 236 residents answered affirmatively the survey questions 'Do you have tap water stored?' and 'Are you willing to participate in further studies?' Stratified random sampling was used to select 90 participants, each from an individual household, for the stored water study. The stratification was by county and accounted for population size differences between counties; county population size was obtained from the Utah State Department of Health. The remaining 146 qualified survey participants were used as replacement households, who were also selected randomly as needed from within individual counties. Drop-outs (due to inability to contact or no-shows) resulted in all but 20 of the replacement households being used to obtain the 90 participants.

Between 12 January 2012 and 11 February 2012, visits were made to the participants' homes, a series of questions was asked related to water storage (see Table 1), and water samples were collected. Free and informed consent of the participants or their legal representatives was obtained and the study protocol was approved by the Institutional Review Board for Human Subjects of Brigham Young University, Study #X110058, approved 22 February 2011.

Water sample collection

At each residence, between one and four containers were sampled, depending on the type and number of water storage containers available in each participant's home. If multiple containers of the same type were present at the residence, one sample was taken from each of two separate containers. If a residence had three or more types of container and had multiples of each type, only two types of container were tested. Most participants stored only one or two types of container. This protocol ensured that all container types used to store water were represented in the study.

Sample collection, preservation and storage were based on Standard Methods 9060A and 9060B (APHA 1998). To prevent sample contamination, the water container opening was cleansed with an alcohol wipe; sterile gloves were worn; sterile disposable pipettes and sterile sampling bags were used; and samples were transported on ice to the laboratory where they were analyzed for coliforms, *E. coli*, and free chlorine within 30 hours of collection.

Table 1 | Participant questions and response frequency

	Number of samples (%[a])
1. Where is your water stored?	
Basement	153 (64)
Garage	48 (20)
Main living space	20 (8)
Outdoor/other	19 (8)
2. How often do you rotate your water?	
At least every 6 months	21 (9)
Between 6 and 12 months	24 (10)
Greater than 12 months	42 (17)
Never	153 (64)
3. How old is your current water?	
Less than 6 months old	19 (8)
Between 6 and 12 months old	44 (18)
Greater than 12 months old	177 (74)
4. What is the source of your water?	
Indoor faucet	164 (68)
Hose/other	76 (32)
5. Was well or city water used?	
City	225 (94)
Well	15 (6)
6. What type of container is your water stored in?	
19 L (5 gallon) plastic container	68 (28)
2 L soda bottles	53 (22)
208 L (55 gallon) plastic barrel	52 (22)
Plastic juice bottle[b]	31 (13)
Non-food plastic container[b,c]	11 (5)
3.8 L (1 gallon) milk jug[b]	10 (4)
Glass container[b]	8 (3)
454 L (120 gallon) plastic barrel	5 (2)
Bag in box	2 (<1)
7a. Was chlorine bleach added to the water?	
Yes	49 (20)
No	188 (78)
Unknown	3 (1)

[a]Percentage values are rounded.
[b]Containers not recommended for use by FEMA.
[c]Household bleach and laundry detergent containers.

Samples for antimony analysis were collected from residents of Utah County, Utah, USA, who agreed to participate after being contacted through e-mail. These participants were not involved in the water sample collection described above. To qualify for antimony analysis, water samples had to be stored at room temperature in reused clear PET plastic soda bottles and have an accurate filling date (month and year). A total of 16 samples were collected for antimony analysis: 14 samples ranging in age from 6 months to over 2 years, and two samples over 25 years in age.

Coliforms and *E. coli*

Coliforms and *E. coli* sample analysis was performed with Colilert® media (IDEXX Laboratories, Westbrook, ME, USA) (Standard Method 9223B; APHA 1998). This media is based on the enzyme substrate test and blank samples were run with each determination. Undiluted samples (100 mL) were mixed with Colilert® media in sterile 120 mL vessels with sodium thiosulfate and allowed to incubate at 35 °C for 24 hours. Incubated samples were evaluated using the Colilert® Presence/Absence Comparator. Presence of coliforms was indicated by the sample having a yellow color equal to or greater than the yellow color of the comparator. Samples that tested positive for coliforms were examined for fluorescence under a UV light in a dark environment. Samples with fluorescence equal to or greater than the comparator constituted a positive test for *E. coli*.

Free chlorine

Free chlorine was measured by the N,N-diethyl-p-phenylenediamine (DPD) Colorimetric Method, Standard Method 4500-Cl G (APHA 1998). Blank samples were run with each determination. Water samples (10 mL) were placed in a sample cell and reacted with free DPD reagents (HACH Company, Loveland, CO, USA). Light absorbance of samples was measured at 515 nm using a HACH Chlorine Pocket Colorimeter™ II with a programed standard curve. A HACH SpecCheck Color Standard DPD-Chlorine-LR Secondary Gel Standards Kit was used to verify that the standard curve was accurate before samples were measured.

Antimony

After antimony sample collection, water was transferred into 125 mL HNO_3-washed high-density polyethylene bottles, and the water was then acidified with HNO_3 (Omni Trace Ultra™, EMD Chemicals, Gibbstown, NJ, USA). The samples were analyzed using inductively coupled plasma mass spectrometry according to EPA Method 200.8 (EPA 1994). The limit of detection was 0.02 ppb antimony. Analysis was completed at ChemTech-Ford Laboratories, a National Environmental Laboratory Accreditation Program certified laboratory, EPA number: UT00027, in Murray, Utah, USA.

Statistical analysis

Logistic regression was run on the presence or absence of coliforms using the following independent variables: container type, water storage location, water source (within residence), water origin (well or city water), addition of chlorine, and water age. Logistic regression was also performed on free chlorine using the independent variable of water age. Data were analyzed for significance using Statistical Analysis System software version 9.3 (SAS Institute, Inc., Cary, NC, USA). Wald Chi-square test *p*-values are reported and significant differences were defined as $p < 0.05$.

RESULTS

As shown in Table 1, a majority of the 240 containers tested were stored in a basement (64%), filled from an indoor faucet (68%), with water that originated from a city water supply (94%), with no additional chlorine added (78%). Most of the stored water was greater than 12 months old (74%), and most never had been rotated (64%). Furthermore, 62 (26%) of the containers did not meet FEMA guidelines for containers storing tap water. These included milk jugs, and containers that were made of glass or non-food-grade plastic, and plastic containers that previously contained juices.

Coliforms and *E. coli*

Of the 240 water samples, seven (3%) tested positive for coliforms (Table 2). There was no significant correlation between the presence of coliforms and the following variables: container type ($p = 0.44$), water storage location ($p = 0.99$), water source (within residence; $p = 0.95$), water origin (well or city water; $p = 0.98$), addition of chlorine

Table 2 | Coliforms presence/absence based on water storage location, source, origin and container type

Categories	Number of samples positive for coliforms
Water storage location	
Basement	6
Garage	0
Main living space	0
Outdoor/other	1
Water source within residence	
Indoor faucet	7
Hose/other	0
Water origin	
City	7
Well	0
Container type	
19 L (5 gallon) plastic container	1
2 L soda bottles	2
208 L (55 gallon) plastic barrel	1
Plastic juice bottle[a]	1
Non-food plastic container[a,b]	0
3.8 L (1 gallon) milk jug[a]	0
Glass container[a]	2
454 L (120 gallon) plastic barrel	0
Bag in box	0

[a]Containers not recommended for use by FEMA.
[b]Household bleach and laundry detergent containers.

($p = 0.97$), and water age ($p = 0.38$). *E. coli* was not detected in any of the collected water samples.

Free chlorine

Table 3 is based on the 237 water samples that were collected from residents who knew whether they had added chlorine bleach (see Table 1). Of these 237 samples, 49 (21%) did have additional chlorine added by the resident and 188 (79%) did not. Only 22 of the 49 samples still contained free chlorine. For free chlorine, 14 (6%) of the samples were at or over the 4 parts per million (ppm) limit established by the EPA. These samples ranged from 4 to 19 ppm free chlorine. Nine samples did not have chlorine added during the filling process but did contain free chlorine when tested.

Table 3 | Chlorine treatment and free chlorine measurements of water samples

Water sample treatment	Number of water samples (%[a])		
Chlorine added	49 (21)		
No free chlorine		27 (11)	
Free chlorine		22 (9)	
≥ 4 ppm[b]			14 (6)
< 4 ppm			8 (3)
No chlorine added	188 (79)		
No free chlorine		179 (76)	
Free chlorine (all < 4 ppm)		9 (4)	
Total	237 (100)		

[a]Percentage values are rounded.
[b]At ≥4 ppm, free chlorine is above the EPA limit.

There was no free chlorine detected in the seven samples testing positive for coliforms. The participants who had water that tested positive for coliforms did not add chlorine bleach to the water during the filling process. The seven samples testing positive for coliforms came from containers filled from an indoor faucet supplying city water.

Three (43%) of the seven positive coliforms samples were stored in containers that did not meet FEMA guidelines. Containers from which six of the seven (86%) positive coliforms samples were taken were stored in a basement and one container was stored in an outdoor/other location, specifically an outdoor balcony. Glass containers only comprised eight of the 240 containers tested, and two of these were positive for coliforms. Of the eight glass containers used, four had lids sealed to the glass through heat processing and four had unsealed lids. The two glass containers that tested positive for coliforms had unsealed lids and were located at the same residence. The other containers that tested positive for coliforms included two 2 L soda bottles, one 19 L (5 gallon) plastic container, one 208 L (55 gallon) plastic barrel, and one plastic juice bottle.

Logistic regression was performed, modeling the presence of chlorine and how it was affected by storage age. The probability that a container had free chlorine present decreased by 4% ($p = 0.008$; odds ratio $= 0.96$; 95% confidence interval $= 0.93$–0.99) for each month of storage.

Antimony

Antimony concentration in the 16 containers tested ranged from 0.03 to 0.3 ppb antimony; no container exceeded the EPA MCL of 6.0 ppb. The two samples with the highest antimony, 0.1 and 0.3 ppb, were the oldest in age, having been stored for >25 years. The other 14 containers were stored between 6 and 28 months and had antimony ranging from 0.03 to 0.08 ppb.

Water rotation

The average age of stored water was 4.6 years, ranging from 1 day to 9 years. When asked about water rotation, 56 of the 90 participants (62%) indicated they never rotated their water, five participants (6%) only rotated part of their water, and 29 participants (32%) rotated all their water. The average water rotation was 22 months, ranging from 1 month to 8 years.

DISCUSSION

Coliforms and *E. coli*

The 3% of samples testing positive for coliforms is substantially lower than that reported by Wright *et al.* (2009) who found 35% of stored water samples positive for coliforms. However, the study involved a small sample ($n = 50$) from one city.

The lack of correlation between the presence of coliforms and other variables may be due to the small number of samples testing positive for coliforms or the small number of samples in any given variable.

As noted, the seven samples testing positive for coliforms came from containers filled from an indoor faucet supplying city water. Wright *et al.* (2009) reported that the water origin was significant, noting that municipal water was less likely to contain coliforms. The EPA, under the Safe Drinking Water Act, requires water distributed by a city to be free from coliforms, but private wells are not subject to EPA standards (EPA 2011a). The presence of coliforms could be a result of improper cleaning and filling methods.

Although none of the samples tested positive for *E. coli*, some samples may have been contaminated previously. *E. coli* has been shown to survive in drinking water for only 4–12 weeks (Edberg *et al.* 2000). Only eight of the 240 samples in this study were less than 12 weeks old. In addition, the ecological conditions in packaged waters may favor heterotrophic bacteria like *Pseudomonas* over other bacteria groups like *E. coli* (Loy *et al.* 2005).

Free chlorine

Although 79% of the samples did not have chlorine bleach added by the participant (Table 3), most of the participants' water sources were presumably chlorinated by their city water system prior to filling. The free chlorine present in the nine samples that did not have chlorine bleach added was most likely due to chlorination by city water treatment facilities.

It is of concern that 14 samples exceeded the recommended maximum amount of chlorine. Over-chlorination can cause eye and nose irritation and stomach discomfort (EPA 2011b). Greater distribution of information and increased consumer awareness regarding proper in-house chlorination of emergency water, and cleaning and storage of water containers could help consumers ensure the safety of their stored water.

The negative correlation between the age of stored water and free chlorine is consistent with the fact that chlorine is a relatively unstable substance that will decay with time (Vasconcelos *et al.* 1997). Based on a monthly decrease of 4%, at 17 months of storage the probability of chlorine being present in a container to which chlorine was added is 50%. Knowing that chlorine decreases during storage has practical significance for those storing water in used containers. Although water may have been appropriately chlorinated, precaution should be taken to prevent post-source contamination, e.g., by sanitary withdrawal of water and proper closure of larger containers that are accessed multiple times.

Antimony

The antimony results are similar to a study conducted on PET plastic bottles that were stored for 6 months and filled with pristine groundwater containing an average of 1.75 ppt of antimony. The study found that the stored water contained antimony at 0.03 and 0.28 ppb, well below the EPA limit (Shotyk & Krachler 2007). It is probable that larger amounts of antimony leached from the PET plastic containers into the original carbonated fluid contents. More antimony leaches in carbonated beverages than non-carbonated beverages (Shotyk & Krachler 2007; Keresztes *et al.* 2009). Thus, when water is stored in re-used containers, less antimony is available to leach from the plastic.

Water rotation

Factors that limit water rotation may include the size and location of the container and the lack of consumer education regarding the importance of rotation. FEMA & American Red Cross (2004) recommend that water be rotated every 6 months if it is not commercially bottled water. In terms of coliforms, *E. coli*, free chlorine, and antimony this research did not show the importance of water rotation every 6 months, but further research should be conducted that looks at the leaching of other contaminants that may make rotation necessary.

CONCLUSIONS

With respect to coliforms, *E. coli*, chlorine, and antimony, 91% of the non-commercially packaged stored water samples were found to be safe for human consumption. However, 9% of water samples were not considered safe due to over-chlorination or the presence of coliforms. These results generally support the practice of utilizing previously used containers for emergency water storage. Providing consumers with information regarding container preparation, proper in-house chlorination, and proper rotation could help improve the safety of stored water. Water stored in previously used containers for emergency purposes should be studied further to determine the source of coliforms or the presence of other contaminants, such as additional plasticizer compounds, pollutants, and other minerals of concern.

ACKNOWLEDGMENTS

The authors appreciate the funding for this research provided by the USDA Grant Smith-Lever Special Needs Program, Be Ready Utah, the Utah Department of Health, and Utah State University Extension. These organizations did not help in the study design or interpretation of data in the writing of the report, or the decision to submit the article for publication. The authors appreciate the contributions of the following individuals: Chrysti Burton, Dr Frost Steele, Emily DeKam, and Melissa Massey.

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First received 21 July 2014; accepted in revised form 4 February 2015. Available online 5 March 2015