Check for updates

Research Paper

Storage-induced deterioration of domestic water quality

C. C. Nnaji, I. V. Nnaji and R. O. Ekwule

ABSTRACT

Due to the failure of municipal supply systems in many Nigerian cities, residents often resort to long storage of water in large high-density polyethylene (HDPE) tanks in order to reduce water stress. This paper investigated deterioration of the quality of stored water for a period of 35 days. Samples from 20 purposively selected storage tanks in Enugu, Nigeria were collected for analysis. Heterotrophic bacteria, total coliform (TC), enterococci and *Escherichia coli* were present in 85%, 75%, 40% and 61% of the samples, respectively. *E. coli* ($p < 0.001$) and heterotrophic plate count (HPC) ($p < 0.001$) were significantly higher in storage tanks that were also used for rainwater collection than those that were not. HPC and TC counts in tanks that collect rainwater were twice those of tanks that do not, while *E. coli* and enterococci counts in tanks that also collect rainwater were three times those of tanks that do not collect rainwater. The most significant change ($p < 0.001$) in *E. coli* concentration occurred after 15 days of storage. Cleaning of tanks caused significant reduction of TC counts ($p = 0.013$), *E. coli* ($p < 0.001$), HPC ($p < 0.001$) and enterococci ($p = 0.001$). Hence, prolonged storage of water causes significant deterioration of water quality.

Key words | contamination, drinking water, *E. coli*, rainwater, storage tank, tanker

C. C. Nnaji (corresponding author)
I. V. Nnaji
Department of Civil Engineering,
University of Nigeria,
Nsukka,
Nigeria
E-mail: *chidozie.nnaji@unn.edu.ng*

C. C. Nnaji
Faculty of Engineering and Built Environment,
University of Johannesburg,
Johannesburg,
South Africa

R. O. Ekwule
Department of Civil Engineering,
University of Agriculture,
Makurdi,
Nigeria

INTRODUCTION

Access to a microbiologically safe water source has posed a serious problem to developing countries and therefore calls for global concern (WHO 2002). Unavailability of drinking water can result in serious physical and mental discomfort arising from water stress and waterborne diseases. Waterborne diseases are still a major health burden in many parts of the world with an estimated 842,000 annual deaths linked to diarrhoea alone (Chalchisa *et al.* 2017). More than 88% of diarrhoea has been attributed to inadequate water, sanitation and hygiene services (Mushi *et al.* 2018). It has been estimated that about 28–47% of the world's population do not have access to safe drinking water and millions more depend on water sources that are located far away from the house (Pickering & Davis 2012). A greater part of the world's population consumes untreated non-piped drinking water, which usually consists of small water volumes collected and stored in homes (Sobsey *et al.* 2003). Even when households are connected to municipal water supply systems, inadequate water supply resulting from pressure on available water resources has made household water storage inevitable in most developing countries of the world (Trevett *et al.* 2004; Chia *et al.* 2013). Household water storage has also been reported in El Paso County, Texas on the US–Mexican border (Graham & VanDerslice 2007) and Toruń, Poland (Burkowska-But *et al.* 2014) and other parts of the developed world where piped water is unavailable. Although storage of water is practised worldwide, the proliferation of household outdoor water storage tanks in Nigeria is an indication of loss of confidence in the government-operated water supply system. In Enugu,

doi: 10.2166/washdev.2019.151

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

 Journal of Water, Sanitation and Hygiene for Development | 09.2 | 2019

where the study area is located, only 31.3% of the residents are connected to the municipal water supply which supplies water approximately three times a week at an average rate of 2.58 hours per supply window (Nnaji *et al.* 2018). This situation invariably leaves about 70% of the residents with no option but to use water vendors who supply water with tanker trucks. The use of tanker truck as a means of water supply must, of necessity, require extended storage periods.

However, household-level water storage is fraught with many challenges which ultimately results in compromising the quality of water. It has been reported that the process of collection at the water source, transportation to homes, dispensing into the household storage tank, actual storage, dispensing into smaller in-house containers and finally dispensing for consumption represent a chain of weak links through which a wide range of pollutants can enter the domestic water supply (Trevett *et al.* 2004; Mushi *et al.* 2018). In developing countries, where people have to walk up to 2,000 meters to fetch water, it has been reported that the use of uncovered containers coupled with the use of dirty hoses attached to stand pipes is a common practice that increases the possibility of contamination (Yongsi 2010). The hygienic condition of storage vessels and the environment in which they are kept have been identified as the major factors leading to the deterioration of stored water (Harris *et al.* 2013). Factors like temperature, higher levels of airborne particles, increased storage time, choice of storage containers and uncovering of storage vessels further deteriorate water quality (Dunne *et al.* 2001; Musa & Abdelgadir 2014).

Matsinshe *et al.* (2014) observed that long storage time is partly responsible for water quality deterioration in household tanks. Sule *et al.* (2011) reported considerable deterioration of quality of stored water in Illorin, Nigeria as a result of poor hygienic practices and questionable source water. Achadu *et al.* (2013) highlighted the preponderance of microbial contamination in plastic water storage containers in Wukari, Nigeria. This was further corroborated by Chia *et al.* (2013), who reported a correlation between quality of stored water and tank handling practices in Zaria, Nigeria. However, storage of water is inevitable because most households find it less stressful to buy water from water vendors to fill their storage tanks, which are usually between 500 and 2,000 gallons. This relieves them from the stress of fetching water on a daily basis, which is costlier and more time-consuming. Sometimes, however, the water is stored for too long thereby making it unfit for consumption. Studies have also shown that self-help water supply encourages the combined storage of vended water from tanker trucks and collection of water from other sources such as rainfall, which may result in cross contamination (Opryszko *et al.* 2013). The practice of augmentation of tanker truck vended water with rainfall is common in the study area. Hence, the primary objective of the study was to investigate the progressive deterioration of stored water quality. The secondary objective was to ascertain the effect of supplemental rainwater and storage tank washing on the quality of stored water.

METHODOLOGY

The study area is located in Awkunanaw area of Enugu South Local Government Area of Enugu State, Nigeria. This area is semi-urban and was chosen due to the lack of piped water supply. Therefore, it has become normal practice for the residents of this area to purchase water from tankers and store in their water tanks for future use. Several studies have confirmed that water vending using tanker trucks has become common practice in many Nigerian cities (Ahmad 2017). The choice of households was based on certain factors, which include: that the water tanks were of high-density polyethylene (HDPE) type; that they were placed at ground level; and were cleaned at least twice a year. This was informed by the fact that ground level tanks are common in the study area. Even when overhead tanks are used, ground level tanks are used as holding tanks for pumping to overhead tanks. Hence, every household that has an overhead tank must, of necessity, have a ground level tank since tanker trucks cannot dispense water in overhead tanks. Besides, ground level tanks are easier to access than overhead tanks located several metres above the ground. Water samples were aseptically collected from storage tanks belonging to 20 purposively selected households using a brand new 1-litre container rinsed with distilled water and then rinsed with sample water. Samples were drawn from spigots fitted at the base of the storage tanks. All water tanks sampled

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

ranged between 500 and 1,000 gallons. Information on capacity of tank, frequency of refill by tanker trucks, frequency of cleaning and rainwater collection was obtained by oral interview. The water samples were transported to the Public Health Laboratory of the Department of Civil Engineering, University of Nigeria, Nsukka within 3 hours for further analyses. Total coliforms and *E. coli* were determined using the Standard Total Coliform (TC) Fermentation Technique as outlined in the *Standard Methods for the Examination of Water and Wastewater*, sections 9221B and 9221F, respectively (APHA 1971, 2005). Enterococci were determined using the multiple tube technique (9230 B) while total live heterotrophic bacteria were determined using the heterotrophic plate count (HPC – 9215B). The concentrations of TC, *E. coli* and enterococci were enumerated using the most probable number (MPN) while HPC was expressed as colony forming units (CFU). The remaining water samples were kept in the laboratory at room temperature and repeat analyses were performed on the water samples after 5 days, 10 days, 15 days, 20 days and 35 days. Preliminary field surveys revealed that the storage period of water at households ranged from 1 to 30 days.

Results of laboratory analyses were subjected to analysis of variance to ascertain whether length of storage, frequency of tank washing and collection of rainwater had any significant effect on water quality at 95% confidence limit. Where a significant effect was confirmed, Tukey's honestly significant difference (HSD) post hoc multiple comparison test was further employed to identify the source of variance. Tukey's post hoc multiple comparison test is a statistical check normally used to ascertain difference or similarity between different groups by measuring the distance between them. It circumvents the limitation of the traditional analysis of variance (ANOVA) which cannot provide detailed information on differences among the various study groups, or on complex combinations of study groups (McHugh 2011).

RESULTS AND DISCUSSION

Variation of water quality with length of storage

All four indicators of water quality were present in most of the water samples analyzed. Live heterotrophic bacteria, TC, enterococci and *E. coli* were present in 85%, 75%, 40% and 61% of the samples, respectively. The average *E. coli* count was 3 MPN/100 mL on the 1st day and 8 MPN/100 mL on the 35th day. HPC averaged 5 CFU/mL on the 1st day and 31 CFU/mL on the 35th day. The average TC and enterococci count were 4 and 3 MPN/100 mL on the 1st day, increasing to an average of 69 and 114 MPN/100 mL, respectively, at the end of the storage period. The maximum indicator organism count at the end of the storage period was 11, 460 and 1,100 MPN/100 mL for *E. coli*, TC and enterococci, respectively. These concentrations of indicator organisms are in gross violation of the 0 MPN/100 mL stipulated for *E. coli*, total coliforms and enterococci in drinking water and therefore conclusively confirm widespread microbial contamination. Regarding the TC count, 75% of the water samples were unfit for human consumption. HPC increased significantly ($p = 0.009$) from the 1st day to the 35th day with a mean value of 113.5 MPN/100 mL. Significant increase ($p = 0.009$) in HPC was first observed after 15 days of storage. Singh *et al.* (2013) reported that HPC and TC were present in storage vessels in South Africa in quantities large enough to pose a risk of microbial infection. There was significant increase of indicator organisms, especially enterococci and TC, in the water samples over the storage period. Enterococci count was the highest of all the indicator organisms at the end of the study period. Addo *et al.* (2016) recorded enterococci increase of 112–180% in sachet water stored at room temperature. It is important to clarify at this point that the main source of water for all the households investigated is water supplied by truck tankers. Because water vending by tanker trucks is primarily a profit-driven venture, most owners of these trucks pay very little attention to the trucks in terms of maintenance and hygiene. The trucks usually look very old and overstretched. Figure 1 shows a typical example of the dilapidated and untidy state of the tanker trucks used in Enugu State. The hoses are usually dirty and leaky, and laid on bare ground during water dispensing. It has been reported that pathogens can intrude into water through leaky pipes/hoses and leakage of valve seals in storage tanks (Chalchisa *et al.* 2017). The dipping of the hose into the tank, as shown in Figure 1(d), is also a possible source of introducing pathogens into water stored in the tank.

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

Figure 1 | Images showing a typical water dispensing/refilling activity by tanker trucks.

There is also a high possibility of contact between the hand of the assistant and water in the tank, thereby contaminating the water.

A significant increase in coliform count was observed between the 1st day and the 35th day with a mean difference of −66.1 MPN. The gradual but certain increase in coliform count over the storage period provides enough grounds to discourage long storage of water in homes. Graham & VanDerslice (2007) reported that water stored for a prolonged period is likely to test positive for total coliforms. One of the major problems with storing water in large domestic vessels is that the water is stagnant and therefore provides a conducive situation for the growth of biofilms in general and pathogens in particular. Although TC was generally higher than *E. coli*, the change in *E. coli* became statistically significant ($p = 0.008$) on the 15th day of storage as against 35 days of storage for coliform (Table 1). It is not exactly clear why this is so, but other studies have reported dramatic increase in autochthonous flora in stored water between 0 and 14 days (Kerr *et al.* 1999). This has been attributed to the presence of organic carbon as an energy source as well as enrichment of the water sample with oxygen by opening of the containers and dispensing for analyses. Generally, there was a statistically significant difference in *E. coli* count over the storage period ($p < 0.001$). Enterococci increased from an average of 3 MPN/100 mL on the 1st

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

Table 1 | Multiple comparison table for water quality parameters

		Mean difference (I-J)						Homogenous subsets				
		(I) day										
Parameter	(J) day	0	5	10	15	20	35	1	2	3	4	5
Coliform ($p = 0.00$)	0	0	2.85	4.1	9.6	17.05	66.10*	2.2				
	5	−2.85	0	1.25	6.75	14.2	63.25*	5.05				
	10	−4.1	−1.25	0	5.5	12.95	62.00*	6.3				
	15	−9.6	−6.75	−5.5	0	7.45	56.50*	11.8				
	20	−17.1	−14.2	−12.95	−7.45	0	49.05*	19.25				
	35	−66.10*	−63.25*	−62.00*	−56.50*	−49.05*	0		68.3			
E. coli (0.00)	0	0	1.25	2.5	3.65*	4.65*	6.00*	0.9				
	5	−1.25	0	1.25	2.4	3.40*	4.75*	2.15	2.15			
	10	−2.5	−1.25	0	1.15	2.15	3.50*	3.4	3.4	3.4		
	15	−3.65*	−2.4	−1.15	0	1	2.35		4.55	4.55	4.55	
	20	−4.65*	−3.40*	−2.15	−1	0	1.35			5.55	5.55	
	35	−6.00*	−4.75*	−3.50*	−2.35	−1.35	0				6.9	
Enterococci ($p = 0.008$)	0	0	1.1	3.1	9.05	27.25	113.5*	0				
	5	−1.1	0	2	7.95	26.15	112.4*	1.1				
	10	−3.1	−2	0	5.95	24.15	110.4*	3.1				
	15	−9.05	−7.95	−5.95	0	18.2	104.4*	9.05				
	20	−27.3	−26.15	−24.15	−18.2	0	86.2	27.25	27.25			
	35	−113.5*	−112.4*	−110.4*	−104.4*	−86.2	0		113.5			
HPC ($p = 0.00$)	0	0	4	8.25	13.75*	18.10*	25.95*	4.6				
	5	−4	0	4.25	9.75	14.10*	21.95*	8.6	8.6			
	10	−8.25	−4.25	0	5.5	9.85	17.70*	12.85	12.85	12.85		
	15	−13.75*	−9.75	−5.5	0	4.35	12.20*		18.35	18.4		
	20	−18.10*	−14.10*	−9.85	−4.35	0	7.85			22.7	22.7	
	35	−25.95*	−21.95*	−17.70*	−12.20*	−7.85	0				30.6	

*The mean difference is significant at 95% confidence level.

day to an average of 114 MPN/100 mL at the end of the storage period. Enterococci are usually preferred as indicator organisms because of their ubiquity in human faeces and their persistence in the environment (Boehm & Sassoubre 2014). Although enterococci are present in the faeces of warm-blooded animals, some may occasionally originate from the soil in the absence of faecal pollution (WHO 2011). The number of enterococci in the water samples was generally higher than *E. coli* count. WHO (2011) noted that the number of intestinal enterococci in human faeces are generally about an order of magnitude lower than those of *E. coli*. However, the presence of *E. coli* and enterococci in the water samples point to contamination with faecal matter. The water quality objective for humanitarian relief specifies no *E. coli* per 100 mL. Although *E. coli* is not pathogenic, a certain strain of *E. coli* (O157:H7) has been reported to be fatal (Saxena *et al.* 2015). Multidrug-resistant *Enterococcus* strains have also emerged as leading causes of hospital-acquired infections (Boehm & Sassoubre 2014). The presence of indicator organisms in the stored water samples is usually an indication of the possibility of the presence of pathogens in water and, therefore, calls for detailed screening for pathogenic organisms.

Effect of rainwater collection on quality of stored water

Forty per cent (40%) of the water tanks investigated were used for both tanker water and rainwater collection. The relatively higher cost associated with the purchase of vended water has resulted in the search for an alternative supply. Hence, some households supplement the truck tanker water supply with rooftop harvested rainwater. Generally, indicator organisms were found to be greater in storage tanks that were also used for rainwater collection than

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

Table 2 | Effect of rainwater collection on stored water quality

	Mean		Std dev.		Maximum		Minimum			
	TRW	TW	TRW	TW	TRW	TW	TRW	TW	Significance ($\alpha = 0.05$)	F
E. coli	5.29	1.83	3.85	2.62	11	7	0	0	0	29.59
TPC	21.01	9.17	15.92	10.01	31	78	1	0	0	21.02
Coliform	23.9	11.19	60.62	16.01	460	75	0	0	0.156	2.04
Enterococci	34.83	11.9	142.84	37.94	1,100	210	0	0	0.28	0.28

TRW, tanks that receive both tanker water and rainwater; TW, tanks that receive only tanker water supply.

in those that were not. However, while *E. coli* ($p < 0.001$) and HPC ($p < 0.00$) were significantly higher in storage tanks that collect rainwater, there was no statistically significant difference between TC ($p = 0.156$) and enterococci ($p = 0.28$) counts of storage tanks that collect rainwater and those that do not (Table 2). Table 2 shows that the average *E. coli* and enterococci counts in tanks that also collect rainwater were three times those of tanks that do not collect rainwater. Also, HPC and TC counts in tanks that collect rainwater were twice those of tanks that do not. Abdellah *et al.* (2012) linked the occurrence and growth of coliform bacteria in water distribution systems to rainfall. Studies have shown that although rainwater is pure when released from the sky, its quality is significantly impacted by environmental factors. Several studies have identified a high concentration of pollutants in rooftop harvested rainwater which can be traced to roof materials, conveyance systems, bulk deposition of pollutants on rooftop and atmospheric contaminants (Chubaka *et al.* 2018). Gusts of wind can sometimes deposit dust particles and bacterial spores on roof and rainwater collection gutters which are subsequently washed into the tank during rainfall. The preponderance of microbial contamination of rooftop harvested rainwater has been the subject of several scientific studies (Ahmed *et al.* 2011; Onyango *et al.* 2018). Rooftop rainwater harvesting, as practised in the study area and many other parts of the country, provides several avenues for water contamination. The usual practice is to form gutters around the edge of the roof using galvanized roofing sheets to channel water falling on the roof to a storage tank. The conveyance system from the roof to the storage tank is usually made of PVC pipe or folded galvanized roofing sheet which empties collected water into the storage tank. This method of collection requires that the tank must be uncovered during the rainy season for rainwater to flow into the tank, thus increasing the chance of water contamination. The most critical season is the onset of the rainy season when accumulated contaminants on the rooftop and the conveyance system are washed into the storage tanks.

Effect of cleaning/flushing on water quality

Frequency of cleaning has a significant effect on TC ($p = 0.013$), *E. coli* ($p < 0.001$), enterococci ($p = 0.001$) and HPC ($p < 0.001$) at 95% confidence level, as shown in Figure 2. Over time, biofilm accumulates inside storage tanks thereby constituting a viable source of water pollution. Biofilms are complex, natural assemblages of various types of microorganism involved in a multitude of trophic and symbiotic interactions (Peter & Routledge 2018). The formation of biofilm is encouraged by the repeated use of the same container for water storage (Burkowska-But *et al.* 2014). These biofilms are usually dislodged from the walls and bottom of the tank by the jetting action of water from the tanker truck hose during refilling, and during handling of containers (Chia *et al.* 2013). Cleaning helps to flush out biofilms and dirt on the walls and bottom of the tanks. The lowest count of indicator organisms was found in tanks that do not collect rainwater and are cleaned at intervals of one month and one and half months (Figure 2). Generally, the presence of indicator organisms increased as cleaning frequency decreased. Frequent cleaning/flushing of storage tanks can be effective in controlling the quality of stored water considering that the quality of source water cannot always be guaranteed. Hence, if residual water from the previous supply was questionable, it would

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

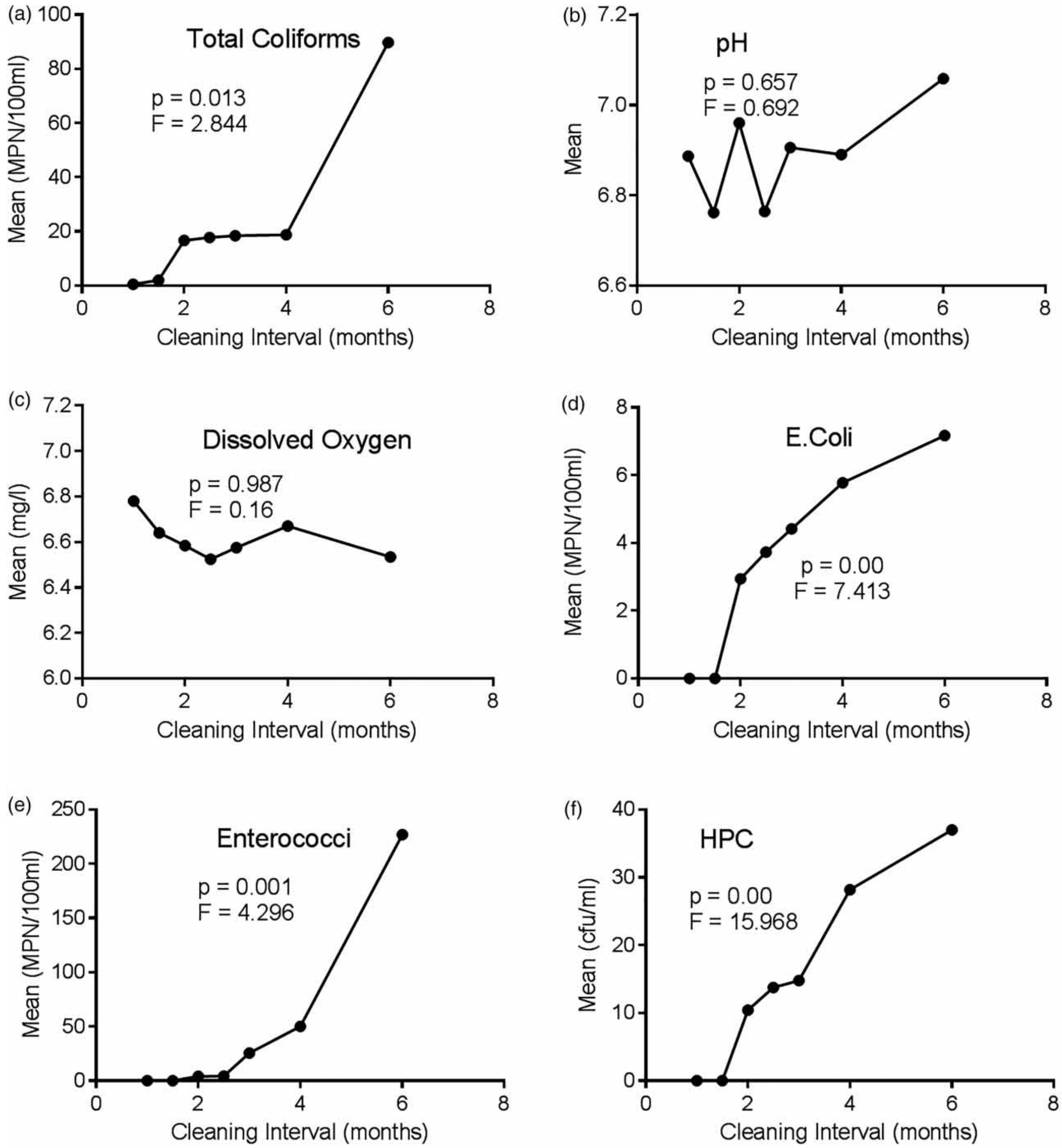

Figure 2 | Effect of frequency of cleaning on water quality.

compromise the integrity of the fresh supply if not flushed out. Singh *et al.* (2013) observed that households in South Africa which were served by water tankers received water of poor quality prior to further deterioration during storage. Because of uncertainties regarding the quality of tanker truck water, it would be safer to clean the tank before each refill in order to avoid transfer of contaminants from the previous supply. Water storage tanks can be cleaned using mechanical scrubbers, water jets, vacuum cleaners, special chemicals or by manual scrubbing using mops or brooms dedicated to that purpose. Obviously, the latter method is very time-consuming and cannot be as effective as the other methods mentioned here. However, regardless of the method of cleaning employed, storage tanks must be washed regularly. In addition, where possible, routine monitoring of stored water quality can provide sufficient evidence

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

of water quality deterioration and the need for washing of storage tanks. It is understood that this quality control measure may not be feasible in developing countries because of limited laboratory resources. However, rapid water testing kits, such as the Oxfam DelAgua field test kit, the DipTest and Multiplexed paper test strip have been developed for on the spot assessment of water quality (Hossain *et al.* 2012; Gunda *et al.* 2017; Kassie & Hayelom 2017). In addition to washing, adequate precautions must be adopted by tank users in order to minimize contamination. Such precautions include always keeping the tanks tightly covered, preventing dipping of vessels into tanks, avoiding contact between stored water and human hand or tanker truck hose especially during refilling.

CONCLUSION

This study has shown that prolonged storage of water in household storage tanks leads to significant deterioration of water quality. It was also found that storage tanks that were used for storing both tanker water and rainwater exhibited a higher degree of contamination than those that were used for storing tanker water only. The bacteriological quality of stored tanker water can be improved by ensuring frequent cleaning of the tanks. Where convenient, cleaning of storage tanks should be undertaken before each refill. It is recommended that water stored in household tanks should be boiled before consumption. In addition, there should be regular dosing of the tanks with affordable and readily available disinfection products such as WaterGuard (4 ml/L for 30 minutes) by storage tank owners after each refill. Further studies should focus on identification of specific routes by which contaminants are introduced into storage tanks as well as detailed investigation of water quality of vended water in the study area.

REFERENCES

Abdellah, A. M., Abdel-Magid, H. O. & Yahia, N. A. 2012 Assessment of drinking water microbial contamination in Al-Butana region of Sudan. *Journal of Applied Sciences* **12**, 856–862.

Achadu, O., Ako, F. & Dalla, C. 2013 Quality assessment of stored harvested rainwater in Wukari, Northeastern Nigeria: impact of storage media. *Journal of Environmental Science, Toxicology and Food Technology* **7** (5), 25–32.

Addo, M., Woods, L., Andoh, L. & Obiri-Danso, K. 2016 Effects of varying storage temperatures on the microbiological quality of street sold water in the Kumasi Metropolis, Ghana. *Research Journal of Microbiology* **11**, 56–63.

Ahmad, M. 2017 The role of water vendors in water service delivery in developing countries: a case of Dala local government, Kano, Nigeria. *Applied Water Science* **7**, 1191–1201.

Ahmed, W., Gardner, T. & Toze, S. 2011 Microbiological quality of roof-harvested rainwater and health risks: a review. *Journal of Environmental Quality* **40** (1), 13–21.

APHA 1971 *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, Washington, DC, USA.

APHA 2005 *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, Washington, DC, USA.

Boehm, A. & Sassoubre, L. 2014 Enterococci as indicators of environmental fecal contamination. In: *Enterococci: From Commensals to Leading Causes of Drug Resistant Infection* (M. S. Gilmore, D. B. Clewell, Y. Ike & N. Shankar, eds). Massachusetts Eye and Ear Infirmary, Boston, MA, USA. Available from https://www.ncbi.nlm.nih.gov/books/NBK190421/.

Burkowska-But, A., Kalwasińska, A. & Brzezinska, M. 2014 Bacterial growth and biofilm formation in household-stored groundwater collected from public wells. *Journal of Water and Health* **13** (2), 353–361.

Chalchisa, D., Megersa, M. & Beyene, A. 2017 Assessment of the quality of drinking water in storage tanks and its implication on the safety of urban water supply in developing countries. *Environmental Systems Research* **6** (12), 1–6. DOI 10.1186/s40068-017-0089-2.

Chia, M., Oniye, S. & Wanta, A. 2013 Domestic water quality assessment: microalgal and cyanobacterial contamination of stored water in plastic tanks in Zaria, Nigeria. *European Journal of Scientific Research* **110** (4), 501–510.

Chubaka, C., Whiley, H., Edwards, J. & Ross, K. 2018 A review of roof harvested rainwater in Australia. *Journal of Environmental and Public Health* **2018** (1), 1–14. https://doi.org/10.1155/2018/6471324.

Dunne, E., Angoran-Benie, H., Kamelan-Tano, A., Sibailly, T., Monga, B., Kouadio, L., Roels, T., Wiktor, S., Lackritz, E., Mintz, E. & Luby, S. 2001 Is drinking water in Abidjan, Cote d'Ivoire, safe for infant formula? *Journal of Acquired Immune Deficiency Syndrome* **28** (4), 393–398.

Graham, P. & VanDerslice, J. 2007 The effectiveness of large household water storage tanks for protecting the quality of drinking water. *Journal of Water and Health* **5** (2), 307–313.

Gunda, N., Dasgupta, S. & Mitra, S. 2017 Diptest: a litmus test for *E. coli* detection in water. *PLoS ONE* **12** (9), 1–13, e0183234. https://doi.org/10.1371/journal.pone.0183234.

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest

Harris, A., Davis, J. & Boehm, A. 2013 Mechanisms of post-supply contamination of drinking water in Bagamoyo, Tanzania. *Journal of Water and Health* **11** (3), 543–554.

Hossain, S. Z., Ozimok, C., Sicard, C., Aguirre, S. D., Ali, M. M., Li, Y. & Brennan, J. D. 2012 Multiplexed paper test strip for quantitative bacterial detection. *Analytical and Bioanalytical Chemistry* **403** (6), 1567–1576.

Kassie, G. & Hayelom, D. 2017 Bacteriological quality of drinking water from source to point of use among rural communities of Farta Woreda in North West, Ethiopia. *African Journal of Microbiology Research* **11** (26), 1069–1074.

Kerr, M., Fitzgerald, M., Sheridan, J., McDowell, D. & Blair, S. 1999 Survival of *Escherichia coli* o157 in bottled natural mineral water. *Journal of Applied Microbiology* **87** (6), 833–841.

Matsinshe, N., Juizo, D. & Persson, K. 2014 The effects of intermittent supply and household storage in the quality of drinking water in Maputo. *VATTEN-Journal of Water Management and Research* **70**, 51–60.

McHugh, M. 2011 Multiple comparison analysis testing in ANOVA. *Biochemia Medica (Zagreb)* **21** (3), 203–209.

Musa, A. & Abdelgadir, A. 2014 Bacteriological evaluation of the drinking water quality in dairy farms in Khartoum state, Sudan. *Journal of Veterinary Medicine and Animal Health* **6** (3), 95–100.

Mushi, M., Mpelasoka, O., Mazigo, H., Mcleod, L., Moremi, N., Mirambo, M. & Mshana, S. 2018 High rate of drinking water contamination due to poor storage in squatter settlements in Mwanza, Tanzania. *Tanzania Journal of Health Research* **20** (3), 1–6. Doi: http://dx.doi.org/10.4314/thrb.v20i3.7.

Nnaji, C. C., Edeh, G. C. & Nnam, J. P. 2018 Status of domestic water supply and prospects of rainwater harvesting in Southeastern Nigeria. *International Journal of Water* **12** (1), 82–102.

Onyango, A., Okoth, M., Kunyanga, C. & Aliwa, B. 2018 Microbiological quality and contamination level of water sources in Isiolo Community, Kenya. *Journal of Environmental and Public Health* **2018** (7), 1–10. https://doi. 1155/2018/2139867.

Opryszko, M., Guo, Y., MacDonald, L., MacDonald, L., Kiihl, S. & Schwab, K. 2013 Impact of water-vending kiosks and hygiene education on household drinking water quality in rural Ghana. *American Journal of Medical Hygiene* **88** (4), 651–660.

Peter, A. & Routledge, E. 2018 Present-day monitoring underestimates the risk of exposure to pathogenic bacteria from cold water storage tanks. *PLoS ONE* **13** (4), 1–21, e0195635.

Pickering, A. & Davis, J. 2012 Freshwater availability and water fetching distance affect child health in sub-Saharan Africa. *Environmental Science and Technology* **46**, 2391–2397.

Saxena, T., Kaushik, P. & Mohan, N. 2015 Presence of *E. coli* o157: H7 in water sources: an overview on associated diseases outbreaks and detection methods. *Diagnostic Microbiology and Infection* **82** (3), 249–264.

Singh, U., Lutchmanariyan, R., Wright, J., Knight, S., Jackson, S., Langmark, J., Vosloo, D. & Rodda, N. 2013 Microbial quality of drinking water from groundtanks and tankers at source and point-of-use in eThekwini Municipality, South Africa, and its relationship to health outcomes. *Water SA* **39** (5), 663–673.

Sobsey, M., Handzel, T. & Venczel, L. 2003 Chlorination and safe storage of household drinking water in developing countries to reduce waterborne disease. *Water Science and Technology* **47**, 221–228.

Sule, I., Agbabiaka, T. & Akomolafe, A. 2011 Bacteriological quality of water stored exteriorly in storage tanks. *Research Journal of Environmental Science* **5**, 603–610.

Trevett, A., Carter, R. & Tyrrel, S. 2004 Water quality deterioration: a study of household drinking water quality in rural Honduras. *International Journal of Environmental Health Research* **14** (4), 273–283.

WHO 2002 *Managing Water in the Home: Accelerated Health Gains From Improved Water Supply*. World Health Organization, Geneva, Switzerland.

WHO 2011 *Guidelines for Drinking-Water Quality*, 4th edn. World Health Organization, Geneva, Switzerland.

Yongsi, H. 2010 Suffering for water, suffering from water: access to drinking-water and associated health risks in Cameroon. *Journal of Health, Population and Nutrition* **28** (5), 424–435.

First received 21 September 2018; accepted in revised form 18 January 2019. Available online 1 March 2019

Downloaded from http://iwaponline.com/washdev/article-pdf/9/2/329/643667/washdev0090329.pdf
by guest