Water quality problems associated with intermittent water supply

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Abstract A controlled study was conducted in Lebanon over a period of 12 months to determine bacterial regrowth in a small network supplying the Beirut suburb of Naccache that had a population of about 3,000. The residential area, which is fed by gravity, is supplied twice a week with chlorinated water from two artesian wells of a confined aquifer. A significant correlation was detected between the turbidity and the levels of heterotrophic plate count bacteria (HPC) in the samples from the distribution network as well as from the artesian wells. However, a negative significant correlation was found between the temperature and the HPC count in the samples collected from the source. A statistically significant increase in counts, possibly due to regrowth, was repeatedly established between two sampling points lying on a straight distribution line but 1 km apart. Faecal coliforms were detected in the source water but none in the network except during a pipe breakage incident with confirmed Escherichia coli reaching 40 CFU/100 mL. However, coliforms such as Citrobacter freundii, Enterobacter agglomerans, E. cloacae and E. skazakii were repeatedly isolated from the network, mainly due to inadequate chlorination. A second controlled study was conducted to determine the effect of storage on the microbial quality of household storage tanks (500 L), which were of two main types – galvanized cast iron and black polyethylene. The mean bacterial count increased significantly after 7 d storage in both tank types. A significant difference was found in the mean HPC/mL between the winter and the summer. Highest counts were found April–June although the maximum temperature was reported later in the summer. A positive correlation was established between the HPC/mL and pH, temperature and storage time.

Keywords Intermittent supply; regrowth; storage; water quality

Introduction
Lebanon, unlike most Middle Eastern countries, has a high annual rainfall and is considered a rich country in water resources, but its capital, Beirut, is suffering from a deficiency of water supply especially during summer and autumn. The problem of water shortage facing most countries in the region is minimised by implementing an intermittent water supply strategy, but its effect on water quality at the point-of-use has not been documented. During days without supply, residents use rooftop tanks made of metal or plastic materials for the transient storage of household water. The objective of a public water supply has always been to produce a product of minimal health risk. The hygienic quality of drinking water can be reduced if pathogenic microbes penetrate water treatment or if the conditions in the distribution network enhance microbial growth (Miettinen et al., 1997). Moreover, the variation in the water quality has been correlated with the age of water (Momba et al., 2000) and water retention (Gibbs et al., 1990). High levels of HPC were reported in water samples collected from a dead end region with low flow conditions (Carter et al., 2000) and in parts of the network with prolonged water retention time and in storage units (Kerneis et al., 1995). The current study aimed at determining factors that may contribute to the deterioration of the water quality in networks operating with an intermittent supply strategy.

Materials and methods
Sampling program
Samples were collected over a period of two years (1999–2000) from a small network supplying the Beirut suburb of Naccache (70–150 m above sea level, population c3000).
This residential area, fed by gravity, was supplied twice a week from underground water originating from two artesian wells of a confined aquifer designated as the upper and the lower wells. Consumers receive water after it has been chlorinated and mixed in a 40 m³ roofed-reservoir. Seven to eight monitoring stations were chosen in the study area. Naccache Arab was the first residential building on the distribution system while Palm building was the last point on the network. Both lay on a straight line about 1 km apart. Polyethylene and cast iron tanks (0.5 m³) were installed in series on the campus of the Lebanese American University (LAU), Byblos, Lebanon. The influent water to the tanks, taken from an LAU-owned artesian well, was treated with rapid sand filtration and UV. The treated water was pumped to a reservoir and from there water flowed by gravity into the distribution network. Bottom effluent sampling from the storage tanks was done with samples collected on d 0, 2, 3, 4 and 7.

**Enumeration of coliforms**

Samples for bacteriological analysis were collected in sterile 2 L polypropylene bottles containing sodium thiosulphate, and coliforms enumerated using the membrane filtration procedure (100 mL; 0.45 µm Millipore; Nalgene equipment) (HMSO, 1994). Filters were placed on membrane lauryl sulphate agar (LSA; Oxoid), incubated at 28°C for 2 h followed by 37°C (total coliforms, TC) and 44°C (faecal coliforms, FC) for 24 h. Presumptive TC and FC were identified using API 20E (BioMerieux) strips and the Biolog system (Biolog Inc.).

**Enumeration of HPC (heterotrophic plate count) bacteria**

HPC bacteria were enumerated on R2A agar (Oxoid; Reasoner and Geldreich, 1985) by filtration through a gridded 0.45 µm Millipore membrane. Identification of the HPC bacteria was done using the API-20NE (BioMerieux) strips and the Biolog system (Biolog Inc.). Chlorine was determined by the DPD method using a Hach colorimeter.

**Statistical analysis**

The SPSS software package was used for statistical data analysis. Statistical log transformation was performed for the bacteriological data to decrease the variance and produce normal distribution populations (LeChevallier et al., 1987; McFeters et al., 1993). Correlation analysis was done to determine the effect of the different parameters on each other and on the HPC/mL of the water in the distribution system.

**Results**

**Water quality in the artesian wells**

Source water samples showed sporadic high turbidity levels in the lower well. Sand erosions in the lower well following periods of heavy rainfall were more frequent during the first year of the study (1999). The mean turbidity value reported in the samples from this well was 9.2 NTU with a maximum of 70 NTU during the winter. A positive significant correlation at $P = \leq 0.05$ was established between log HPC/mL and turbidity level. The average HPC in the samples from the lower well was 81/mL while values as high as 2,000/mL were reported during the winter. A negative significant correlation was detected between HPC counts and temperature.

**Effects of physicochemical parameters on HPC counts**

Higher turbidity values were detected during the winter as compared to the summer. There was a significant positive correlation at $P = \leq 0.05$ between log HPC/mL and turbidity. Samples collected in the summer had significantly higher mean total residual chlorine than samples collected in the winter. A negative significant correlation at $P = \leq 0.05$ was detected...
between total residual chlorine and log HPC/mL. However, no significant correlation was established between the log HPC/mL and the prevailing temperature in the network and also no significant difference was detected in the mean HPC/mL between the summer and winter sampling seasons. An increase in the log HPC/mL was concomitant in most cases with the increase in the water turbidity in the distribution system (Figure 1).

The total residual chlorine, which in most cases was <0.5 mg/L, effectively controlled the level of HPC in the range of 30–100/mL. Intermittent flow patterns led to sudden changes in the HPC with values as high as 7,000/mL being sporadically detected at the different sampling points. A seasonal variation was not established, with the maximum being reported during the winter. Contrary to the increase in the water temperature during July–September, there was a decrease in HPC. Gram-negative, oxidase positive, non-fermenting bacteria were dominant in the distribution network. The following were repeatedly isolated: Pseudomonas aeruginosa, Flavobacterium, Serratia, Sphingomonas, Xanthomonas, Aeromonas. Gram-positive organisms, including Gordona, Rhodococcus, Bacillus and Staphylococcus, were also isolated but at a lesser frequency.

Total and faecal coliforms

TC and FC were detected in samples from the artesian wells and the distribution network. E. coli was the most frequent type detected in the samples from the lower underground well with the majority being isolated during the winter. However, the coliform Citrobacter freundii was the most common type in the samples from the network being isolated mainly during the winter season. Leakage, following pipe breakage at one of the sites on the network, led to an increase in the HPC count and a remarkably high number of faecal (40 E. coli/100 mL) and total coliforms.

Regrowth in the distribution system

Regrowth, defined as the multiplication of HPC bacteria, was obvious between two selected sampling points in the network lying on a straight line but 1 km apart. Naccache Arab sampling site, the first point in the network receiving water, had a significantly lower HPC count compared to the Palm building site, the last point receiving water in the studied network (Figure 2).

Regrowth in the storage tanks

Water stored in both types (cast iron and polyethylene) of household tanks underwent significant deterioration in the bacteriological quality after storage. Single factor ANOVA
revealed the presence of a significant difference (P ≤ 0.05) between the HPC for the water at day 0 compared to the stored water. The difference in the HPC count was not significant between both types of household tanks. The average HPC/mL in the household tanks was higher in the summer as compared to the winter. The mean log HPC of the UV-treated underground water increased by one order of magnitude during the 7 d storage period (Figure 3). The following genera of Gram-negative, oxidase positive, non-fermenting bacteria were dominant in the storage tanks: Sphingomonas, Xanthomonas, Flavobacterium and Pseudomonas.

**Discussion**

In addition to standard parameters, such as temperature, chlorine and turbidity, that were normally used to assess factors controlling regrowth in the distribution system, we have investigated the impact of the intermittent water supply strategy on the water quality. Sand erosions in the source water following periods of heavy rainfall resulted in high turbidity that correlated with the higher counts in the distribution system. Bucklin et al. (1991) reported that periodic occurrence of elevated turbidity in finished drinking water could have serious implications in the effective treatment of potable water. An 8-fold decrease in the efficiency of disinfection was reported when the level of turbidity increased from 1 to 10 NTU (Le Chevallier et al., 1981). McCoy and Olson (1986) conducted a study on samples collected from the municipal drinking waters in southern California showing that turbidity was highest following periods of heavy rainfall.
A uniform level of residual chlorine was not maintained in the investigated network with values fluctuating (0–1.4 mg/L). Maintenance of a disinfectant residual in the distribution system is important to produce conditions that are unfavorable for bacterial survival in drinking water (LeChevallier et al., 1996). A negative significant correlation was established in this study between the HPC/mL and the total residual chlorine.

Very high HPC and turbidity (data not shown) values were detected after flow interruption and immediately as flow restarted. As the pressure was not maintained in the network during flow interruption, the intermittent supply resulted in repeated contamination of the water by infiltration and/or water stagnation. Carter et al. (2000) showed that the elevated level of HPC at dead-end regions was mainly due to water stagnation. Thus, the problem with intermittent distribution is that water piped into the system is breached and a constant pressure is not maintained which frequently leads to the recontamination of treated water (Cotruvo and Trevant, 2000; Zacheus et al., 2001).

Although LeChevallier et al. (1996) emphasized the importance of temperature in controlling microbial growth in drinking water networks, we found no significant correlation between HPC/mL and temperature throughout the study period. The lack of any correlation between the two parameters could be attributed to the elevated turbidity levels during the winter, the high residual chlorine during the summer and the intermittent supply.

Pigmented bacteria were the dominant types among the HPC population recovered from the network as well as from the storage tanks. Reasoner et al. (1989) illustrated that some of the pigmented bacteria were opportunistic pathogens and their presence in the network was evidence they were more chlorine tolerant than the non-pigmented forms. Leaks, along with non-uniform chlorination, were additional factors that led to deterioration of the water quality as manifested by the detection of E. coli spikes in the network. Geldreich et al. (1992) revealed that any disturbance in the distribution network might provide a contamination pathway from storm water runoff or sewage infiltration while Le Chevallier et al. (1996) considered the presence of E. coli and the high incidences of coliforms in distribution systems as an indication of possible cross-connection or breakdown of the disinfection barrier.

This study also showed that retention of water in household tanks had a significant effect on the stored water quality. A significant increase in the HPC count was found upon storage of treated water up to 7 d. These HPC comprised known opportunistic microorganisms and thus may have posed a potential health hazard. Similarly, Geldreich et al. (1975) detected a significant decline in emergency water quality upon storage while Kerneis et al. (1995) showed that reservoirs in which water had an elevated residence time could significantly influence the level of the HPC bacteria.

**Conclusion**

The intermittent mode of water supply in Lebanese networks, associated with changes in pressure, water stagnation, infiltration, line breaks, turbidity, regrowth, non-uniform chlorine residuals and storage in household tanks, was an important factor contributing to the deterioration of potable water quality. Further detailed studies are needed to address these factors in order to alleviate the potential health risks associated with intermittent water supply.

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