Assessment of drinking water quality in regional New South Wales, Australia

S. T. M. L. D. Senevirathna, Andrea M. Goncher and Aaron Hollier

ABSTRACT

There is a substantial research gap relating to the quality of drinking water in regional Australia and identifying possible improvements. In particular, the quality of water available in public places (washing and drinking), such as water bubblers installed in regional parks, schools, rest areas and railway stations, is poorly investigated. This paper discusses the primary and secondary water quality of eight water distribution networks in New South Wales (NSW) regional towns. An analysis of a large number of drinking water samples (more than 11,000) identified that maintaining microbial water quality and the required free chlorine level (>0.2 mg/L) are challenging issues for regional water distribution networks. Sixty-three per cent of the samples collected from the water outlets available in public places of a regional town showed free chlorine levels of <0.2 mg/L, and 30% of samples showed positive results for total coliform. All heavy metal levels of the samples were within the safe level. Water temperature was identified as the most problematic secondary water quality parameter in public water bubblers. Stainless steel was the common material used in bubblers where surface temperatures exceeded 50 °C during summer. This study identifies possible design and operational modifications to improve regional drinking water quality and make public water bubblers more usable.

Key words | drinking water, microbial water quality, regional Australia, water bubblers

S. T. M. L. D. Senevirathna (corresponding author)
Aaron Hollier
CSU Engineering, Faculty of Business, Justice and Behavioural Sciences,
Charles Sturt University,
Panorama Avenue, Bathurst, NSW,
Australia
E-mail: *lsenevirathna@csu.edu.au*

Andrea M. Goncher
Department of Engineering Education,
Herbert Wertheim College of Engineering,
University of Florida,
Gainesville, FL,
USA

INTRODUCTION

The provision of safe and continuously available drinking water is an essential requirement for human health and well-being and community development (Sagehashi & Akiba 2017). There are growing concerns about the quality of water distributed by comparatively smaller distribution networks (Gunnarsdottir *et al.* 2017). This is especially the case in regional towns where the increment of endemic cases of waterborne diseases may not be reported, and health surveillance systems may not be able to detect potential issues (Hrudey *et al.* 2006). Recent literature clearly identifies a correlation between water quality and the capacity of water distribution networks. For example, more than 99% of large water supply systems operated in 23 countries out of 27 European Union member countries meet microbiological compliance targets (Gunnarsdottir *et al.* 2017). However, for small water distribution networks, only three countries out of 27 meet microbiological compliance targets (Gunnarsdottir *et al.* 2017).

There is limited documented research in Australia to demonstrate the quality of water distribution networks that operate in regional towns (Cretikos *et al.* 2009). A few publications suggest the possibility of drinking water contamination with heavy metals, such as copper, nickel and lead in regional areas, particularly at the domestic level (Alam *et al.* 2008; Harvey *et al.* 2016). Several barriers have been identified to maintaining a safe and reliable drinking

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water supply in rural Australia, including limited water supply infrastructure (water treatment plants and distribution networks), limited resources and skilled staff, and inadequate catchment monitoring (Whelan & Willis 2007). Mosley *et al.* (2012) have observed a correlation between river flow levels and some water quality parameters such as salinity, total nitrogen, total phosphorus, chlorophyll and turbidity in several regional locations. Several researchers have argued that the discharge of organic and inorganic pollutants through various land uses in regional Australia makes the provision of safe drinking water more challenging (Thornton 1996; McKay & Moeller 2001). For example, various chemicals and discharge related to agricultural industries, such as fertilizers, pesticides, insecticides and animal hormones, ultimately ended up in water environments and advanced processes are required to eliminate these pollutants from environmental water. Also, these chemicals make significant changes to the aquatic environment, such as causing excessive growth of algae. Uncontrolled and unintentional discharge from the mining industry have also been identified as a main water polluter in regional Australia (Hilson 2006; Wright *et al.* 2011).

The consumer perception of drinking water quality in regional Australia is also under-investigated. A community organization that works with secondary school students in a regional Australian town, identified that public drinking water outlets, such as school water bubblers, are rarely used by consumers. Several reasons are suggested for an unwillingness to use public water bubblers, including bad taste, odour and colour, and a high temperature during summer. A similar situation has been reported in California where more than 50% of middle school students were unhappy with the cleanliness of their water bubblers, 48% were dissatisfied with the taste of the water provided, and 33% had experienced illness due to drinking this water (Patel *et al.* 2014). People's use of public water outlets, such as water bubblers installed in parks and playgrounds, is influenced by several factors, including gender, location, age, household income, marital status and education levels (Park *et al.* 2011). However, the establishment of reliable drinking water outlets in public places, particularly in schools, is essential for public health, well-being, convenience and environmental sustainability. For example, a lack of desirable drinking water sources in schools may lead to students becoming dehydrated and their cognitive performance being weakened (D'Anci *et al.* 2006).

The aim of this paper is to identify drinking water quality issues in regional New South Wales (NSW). Analytical results of more than 11,000 water samples collected (2009–2018) from eight regional water distribution networks are summarized in this paper. Also, the quality of tap water (washing and drinking) available in public places, such as schools and playgrounds in a regional town, is discussed and possible improvements are identified.

METHODS

Water quality parameters

Chemical (aluminium, barium, boron, cadmium, copper, iron, manganese, mercury, molybdenum, nickel, selenium, silver, total hardness, free chlorine and pH), physical (turbidity and true colour) and microbial (*Escherichia coli* and total coliforms) parameters were used to evaluate the quality of drinking water. Water samples were collected, preserved and handled for chemical parameters according to Standards Australia (1998) AS/NZS 5667.1:1998. Sampling for microbial water quality parameters was carried out according to AS 2031:2012 (ISO 19458:2006, MOD). Briefly, sterile and leak-proof 250 ml PET bottles were used to collect samples. Sodium thiosulphate was used to neutralize free chlorine in the water samples. Checks were done to make sure that the tap was clean and in working order before 2–3 minutes of the first flush was discarded and samples were collected. Also, the mouths of the taps ware disinfected with ethanol (70%).

Public water taps

Water samples collected from first flushes of washing and drinking water taps (water outlets) available in parks, playgrounds, public places (a railway station, the city information centre, etc.) and education institutions (schools, university and technical colleges) of a NSW regional town were analysed at CSU Engineering for microbial water quality, free chlorine and total chlorine. Field blanks were used to conform the sample contamination that is negligible during the collection procedure. Prior to analysing the samples, all instruments were calibrated using the procedure given by the manufacturer of the instrument. The USEPA DPD (*N*,*N*-diethyl-*p*-phenylenediamine) method was used with a Hach DR 1900 Spectrophotometer to determine the total and free chlorine levels in the water samples. The Coliscan Easygel method (https://www.micrologylabs.com/page/93/Coliscan-Easygel) was used to determine the levels of total coliforms and *E. coli* in the collected samples. In this method, collected samples were immediately transported to CSU Engineering. Five millilitres of water was sterilely transferred from sample containers into the bottles of Coliscan Easygel. The bottles were swirled to distribute the inoculum and then the mixtures were gently poured into the labelled Petri dishes. The number of colonies was counted after 24 hours of incubation at 35 °C.

Data extraction from the NSW Health drinking water quality database

All water samples reported in this paper were analysed in the CSU Engineering water lab or laboratories accredited to perform such analyses. Procedures for water samples tested outside CSU Engineering used analytical methods approved by the EPA, and those results were directly extracted from the NSW Health (https://www.health.nsw.gov.au) drinking water quality database. Water distribution networks in the central tablelands of NSW were selected for the study (Figure 1). Ten years of water quality data for each network were extracted from the database (2009–2018). The locations of the targeted water distribution networks were within 200 km of the CSU Engineering School in Bathurst. These networks are designed to serve a total regional population of more than 150,000. The number of people who use each distribution network varies from about 5,000 to 38,000. Extracted data were carefully checked, and unrealistic water quality data were identified and eliminated from the analysis. All graphical and statistical computations were made using SPSS (version 25).

RESULTS AND DISCUSSION

Metal levels in drinking water

The metal levels measured in water samples collected from eight water distribution networks are summarized in Table 1. None of the water samples collected from small water distribution networks (<10,000 served population) exceeded any guideline values. All samples collected from other water distribution networks satisfied metal guidelines, except aluminium and iron. Two hundred and forty-four water samples were analysed from water distribution

Councils Map of New South Wales	Council
	Number of water distribution networks: 8 Largest distribution network: serves over 38,000 people Smallest distribution network: serves less than 6,000 people Location of distribution networks: within 200 km of CSU Engineering

Figure 1 | Water distribution networks investigated in this study.

Table 1 | Summary of maximum metal levels measured in samples collected from targeted water distribution networks for the last 10 years

		Capacity (served population)			
Metal	**Guideline value (mg/L)**	**30,000–40,000**	**20,000–30,000**	**10,000–20,000**	**<10,000**
Number of samples		244	124	234	14
Aluminium	0.2 (a)	1.16 (1%)	1.3 (18%)	0.59 (5%)	0.18
Barium	2 (h)	0.068	0.034	0.076	0.01
Boron	4 (h)	0.05	1.4	0.1	0.05
Cadmium	0.002 (h)	0.0014	0.00025	0.0005	0.00025
Copper	2 (h)	1.668	0.193	0.108	0.185
Iron	0.3 (a)	0.22	0.7 (4%)	0.16	0.02
Manganese	0.5 (h)	0.254	0.036	0.072	0.047
Mercury	0.001 (h)	0.0005	0.0005	0.0002	0.0001
Molybdenum	0.05 (h)	0.005	0.0025	0.005	0.0025
Nickel	0.02 (h)	0.01	0.02	0.01	0.005
Selenium	0.01 (h)	0.005	0.009	0.003	0.001
Silver	0.1 (h)	0.005	0.005	0.005	0.001

(a), aesthetic guideline value; (h), the health-based guideline value, the bracket percentage and the percentage exceeding guideline value.

networks with a served population of over 30,000 for metal parameters, and only two samples exceeded the aluminium aesthetic guideline value of 0.2 mg/L. One hundred and twenty-four samples were analysed from the distribution networks with a served population between 20,000 and 30,000 where 22 samples exceeded the aesthetic guideline value for aluminium (the maximum reported level was 1.3 mg/L) and five samples exceeded the aesthetic guideline value for iron (0.3 mg/L). Iron is often elevated in groundwater sources (mainly by weathering of iron-bearing minerals), and aluminium-based coagulant is most commonly used in drinking water treatment and may occasionally result in elevated aluminium concentrations. It is worth noting that the overall metal concentration of the water distribution networks, particularly health-related harmful heavy metal levels, such as arsenic, cadmium and lead, were well within the allowable ranges.

Previous studies have suggested the possible contamination of groundwater, river water and animal tissues with heavy metal by the mining industry in regional NSW. Researchers have measured the high level of cadmium (up to 0.016 mg/L), lead (up to 0.142 mg/L) and zinc (up to 0.025 mg/L) in samples collected from an NSW river (Norris 1986). The main sources of the metal contaminant of this river were seeps and previously deposited particulate material from mine workings. Low *et al.* (2005) have reported the mobility of zinc, cadmium and lead from anthropogenically contaminated soil to plants in western NSW.

Compliance of water quality parameters

The compliance results of selected water quality parameters for eight water distribution networks are shown in Table 2. Maintaining the required free chlorine level in the distribution network has been highlighted as a major operational issue in all water distribution networks. Also, the total hardness level measured in some samples was higher than the aesthetic guideline value. The hardness of water can be caused by dissolved metals, particularly divalent cations of calcium and magnesium, and hard water can lead to scaling in pipes. There is no health-based guidelines value for hardness. Highly increased intake of magnesium salts may cause a change in bowel habits (diarrhoea). Daily consumption of hard water may result in a comparatively higher level of magnesium in coronary arteries, bone and myocardial tissue. Several studies have reported the relationship between the hardness of drinking water and cardiovascular disease (Sengupta *et al.* 2013). Some

Table 2 | Commonly identified water quality parameters, which failed to meet guideline values on some occasions

Capacity (served population)	Characteristic	Guideline	Mean	SD	Min	Max	Number of samples	Meeting guideline value (%)
<10,000	Total hardness (mg/L)[a]	200	144	115	24	523	76	88
	True colour (HU)[a]	15	4	8	1	60	76	96
	E. coli (cfu/100 mL)[b]	0	0	0	0	1	1,757	100
	Free chlorine (mg/L)	0.2–5	0.6	0.5	0	7.2	1,515	76.2
	pH[a]	6.5–8.5	7.9	6.9	6.9	8.7	389	99.2
	Total coliforms (cfu/100 mL)[b]	0	4	22	0	202	1,757	92
	Turbidity (NTU)[a]	5	0.3	0.4	0	6	375	100
10,000–20,000	Total hardness (mg/L)[a]	200	110	32	38	257	124	99
	True colour (HU)[a]	15	1	1	1	7	124	100
	E. coli (cfu/100 mL)[b]	0	0	0	0	12	3,163	100
	Free chlorine (mg/L)	0.2–5	0.7	0.7	0	6	3,054	77
	pH[a]	6.5–8.5	7.7	0.3	5	8.7	2,938	99
	Total coliforms (cfu/100 mL)[b]	0	1	11	0	202	3,163	95
	Turbidity (NTU)[a]	5	0.6	1.9	0	12	2,891	99
20,000–30,000	Total hardness (mg/L)[a]	200	59	30	2	269	376	97
	True colour (HU)[a]	15	3	3	0	19	376	99
	E. coli (cfu/100 mL)[b]	0	0	0	0	12	3,896	99
	Free chlorine (mg/L)	0.2–5	0.8	1.1	0	5.5	3,553	67
	pH[a]	6.5–8.5	7.4	0.7	6.0	8.9	2,466	98
	Total coliforms (cfu/100 mL)[b]	0	4	23	0	202	3,896	90
	Turbidity (NTU)[a]	5	1	1	0	18	1,445	100
30,000–40,000	Total hardness (mg/L)[a]	200	97	37	43	230	153	99
	True colour (HU)[a]	15	2	4	1	41	153	99
	E. coli (cfu/100 mL)[b]	0	0	5	0	20	1,707	99
	Free chlorine (mg/L)	0.2–5	0.4	0.5	0	6.2	1,653	41
	pH[a]	6.5–8.5	7.9	0.4	6.7	9.1	1,534	95
	Temperature (°C)[a]	30	17	5	7	32	173	99
	Total coliforms (cfu/100 mL)[b]	0	1	7	0	200	1,707	93
	Turbidity (NTU)[a]	5	0.2	0.1	0	4	1,479	100

[a]Aesthetic guidelines.
[b]Health-based guidelines.

researchers have suggested a possible association between the risk of gastric cancer and the levels of calcium and magnesium (Yang *et al.* 1998). However, less than 5% of total samples failed to meet the required guideline, and there is insufficient evidence to say that there is hard water toxicity in the targeted areas.

To inactivate microorganisms, chlorination was used in all eight water supply systems investigated in this study. This process has proved its efficiency to destroy disease-causing pathogens, such as bacteria, viruses and protozoans. When chlorine is mixed with water, it is dissociated into hypochlorous acid and hydrochloric acid, which destroy microorganism by oxidating the organic molecules. Trihalomethanes and haloacetic acids are identified as common disinfection by-products, particularly, when the level of natural organic matter is comparatively high in the water.

This paper reports the free chlorine levels measured in more than 11,000 samples collected from various endpoints of eight water distribution networks for the past 10 years. Compared with other water quality parameters, free chlorine levels showed the lowest compliance with the minimum recommended free chlorine residuals. The Australian Drinking Water Guidelines (ADWG) level for free chlorine is 0.5 mg/L. However, a recommendation was made by the NSW Department of Primary Industries Office of Water in consultation with the NSW Health in 2014 to maintain the free chlorine residual level at more than 0.2 mg/L. Among 1,653 water samples collected from large water distribution networks (over 30,000 of the served population), only 678 (41%) samples showed more than 0.2 mg/L of free chlorine. Comparatively better free chlorine levels were reported from water distribution networks with a served population of less than 20,000 where more than 75% of the samples satisfied the minimum recommended free chlorine residual (>0.2 mg/L).

If the variation of free chlorine concentrations in water distribution systems is known, scheduling the re-chlorination is not a big challenge (Kim *et al.* 2014). The destruction of free chlorine in a distribution network is multi-factorial (Chowdhury *et al.* 2009). Previous studies have reported several important factors that impact free chlorine levels in a distribution network, such as temperature (Wang *et al.* 2019), water age (Xu *et al.* 2018), piping material, corrosion and pH (Zhang *et al.* 1992), hydraulic conditions and instantaneous mixing (Mompremier *et al.* 2015), dosage and microbial activity (Zhang *et al.* 2004). Bacteria that detach from pipe biofilm and enter treated water may be inactivated if the disinfectant residual is sufficient. In this case, there is no negative impact on the consumer even though bacterial regrowth has occurred on the pipe surface or recontamination has occurred. On the other hand, if the loss of the disinfectant residual in the treated water is large, as would be true for long water residence times, bacteria that are released from the pipe surface or by recontamination will not be inactivated quickly. In this case, indicator bacteria (e.g. coliforms, *E. coli* and enterococci) may be detected in the treated water and the consumer may be negatively impacted. Comparatively longer retention times and hydraulic conditions are identified as controlling factors for free chlorine levels in large water distribution networks operated in regional NSW.

Water quality in public water taps

Table 3 shows microbial water quality parameters and residual chorine levels measured in public water taps and bubblers installed in playgrounds, parks, public places and educational institutions in a regional town in NSW. These samples were collected from the first flush of each water outlet. A close positive correlation was observed between the free chlorine level and the detection of total coliforms. The safest microbial water quality was detected in parks and playgrounds where 87.5% of the samples showed safe free chlorine levels and only 10% of the samples showed positive results for total coliform. None of the water samples collected from public places, such as the railway station and city information centre, showed safe residual chorine levels, and 65% of the samples showed positive results for total coliforms. About 50% of public taps and water bubblers installed in educational institutions and investigated in this study showed positive results for total coliforms, and just 18% showed safe free chlorine levels. None of the samples collected from public water outlets indicated the potential contamination of *E. coli*.

The variation of the free chlorine level in different locations can be explained by the usage of water outlets. For example, public water outlets installed in parks and playgrounds are frequently used and water retention times in pipes are lower and free chlorine levels are comparatively higher.

It is worth noting that local authorities have already identified the issues with free chlorine levels in the town water distribution network and a significant improvement has been observed in free chlorine levels, particularly since 2017. Figure 2 shows the vitiation of town water free

Table 3 | Water quality parameters measured in public water taps and bubblers in a regional town in NSW

Parameter	Parks and playgrounds	Public places	Educational institutions
No. of water outlets	8	5	11
Total Cl mg/L (mean and SD)	0.90 (0.55)	0.17 (0.11)	0.17 (0.19)
Residual Cl mg/L (mean and SD)	0.71 (0.46)	0.03 (0.03)	0.09 (0.15)
Meeting guideline value (%) 0.2 mg/L of RCl (%)	87.5%	0%	18%
Detection of total coliforms (%)	10%	65%	50%
Detection of *E. coli* (%)	0	0	0

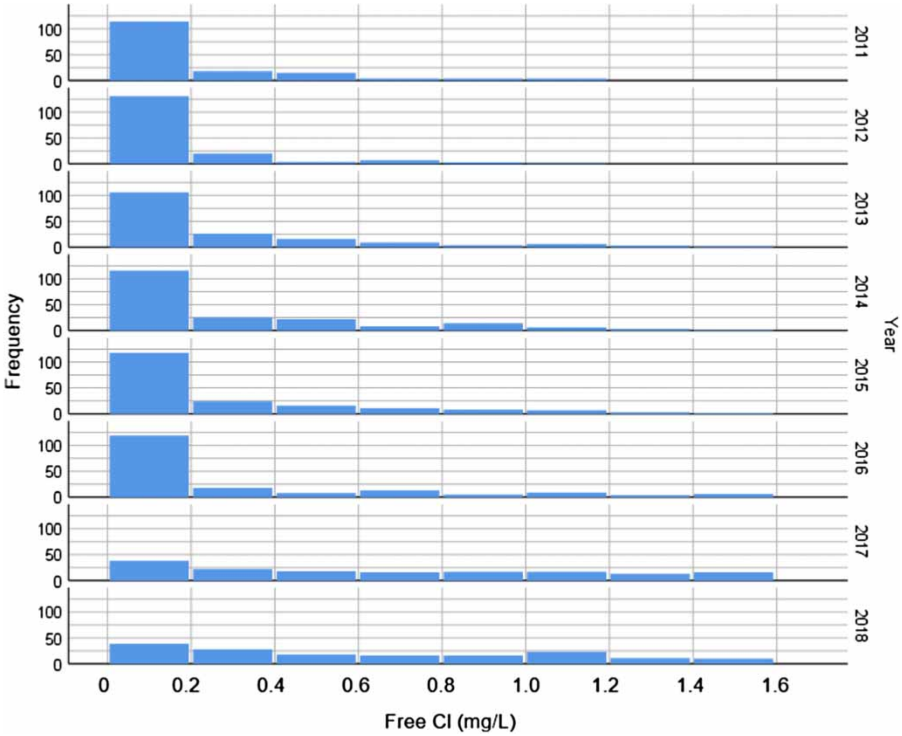

Figure 2 | Vitiation of free chlorine levels with time.

chlorine levels for the last eight years (from 2011 to 2018). Only 26.5% of samples analysed from 2011 to 2012 achieved the minimum recommended free chlorine residual of 0.2 mg/L. In 2014, the Department of Primary Industries Office of Water in consultation with the NSW Health recommended maintaining a free chlorine residual. Improvements were observed in 2015 and 2016 where more than 35% of the samples satisfied the guideline value. The free chlorine level improved significantly in 2017 and 2018 when more than 75% of analysed samples showed more than 0.2 mg/L of free chlorine. However, improvement is still needed and modelling of water distribution networks for free chlorine may be a promising tool to identify potential operational and maintenance measures to maintain free chlorine levels in entire distribution networks.

Temperature

Parents, teachers and community programme leaders of local schools have reported that school water bubblers are rarely used by students and the temperature has been identified as the main issue. Figure 3 shows the variation of daily average, atmospheric temperature, tap water temperature and steel temperature with time. Atmospheric temperature readings were extracted from the local airport meteorology station. Several days in summer 2018 reached more than 32 °C average atmospheric temperature.

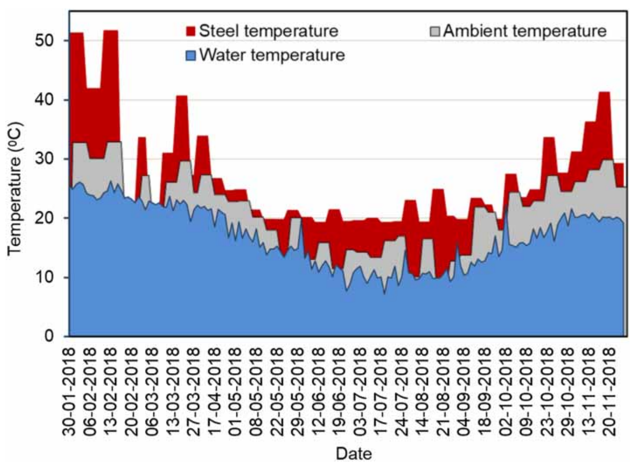

Figure 3 | Variation of atmospheric temperature, tap water temperature and steel temperature with time.

However, the tap water temperature was less than 30 °C throughout the year. Among 173 water temperature readings measured in the last 10 years, only one reading has exceeded the guideline value. The mean water temperature of the town water for the last 10 years is 16.9 °C (SD 5.2) with a minimum of 6.7 °C.

It was noticed that the frames, basin and casing of school bubblers were made with stainless steel and most of them were installed without a cover. Figure 3 indicates the temperature of uncovered stainless steel bubblers may exceed 50 °C in summer. This problem could be easily solved by shading uncovered bubblers or relocating them to more suitable places. Most of the bubblers investigated in this study were poorly maintained, and some of them were not in a usable condition. The selection of correct material (stainless steel, ceramic, carbon, etc.), the correct place of installation, correct design (robust, with treatment facility) and the implementation of proper operational and maintenance plans will make public water bubblers more usable.

Potential improvements

Major challenges identified in regional water distribution networks can be fixed by modifying the design and operational protocols. A calibrated hydraulic model of each water distribution network should be combined with available chlorine decay models to understand the variation of free chlorine levels in the entire water distribution network. This knowledge is helpful to identify problematic areas in the network and develop a re-chlorination schedule to overcome the issue. Modifications are needed to the guidelines relating to the design and installation of public water bubblers. In particular, serious consideration needs to be given to the bubbler basin material, and the place of installation and a regular maintenance programme should be seriously considered. Water outlets in public places for human consumption have been constructed to serve drinking and washing requirements. Design considerations include ergonomics for a range of ages, the angle of flow, the rate of flow, materials used and run-off disposal. Design solutions have been integrated to accommodate the demographics they are serving.

Role of education and public participation

Our review of the literature and study results support the importance of water quality, effects on consumption and the impacts on public health. Water outlets available for use in educational institutions, parks and playground and other public spaces can affect the health of consumers, as well as have secondary effects on consumers, e.g. lack of concentration, from dehydration. Educators, policy-makers, plant managers, researchers and citizens can all influence how water consumption is perceived and undertaken by the public.

Educators and administrators, or those who have authority in the development and enforcement of the policy, should consider the following points to encourage water consumption in educational institutions by students during school hours.

- Teachers, coaches and community programme leaders should encourage students to bring reusable water containers and fill up regularly from bubblers throughout the day; especially before and after activities, or conditions, that lead to dehydration.
- Linking water consumption via reusable containers and water bubblers to pro-environmental behaviours, e.g. recycling, reduced use of resources, provides students with a more holistic view, regarding their role in sustainability concepts.
- Steel bubblers should not be installed for public consumption without shade to help regulate exposure to high temperatures.

Individuals, or groups, who have influence or authority related to the water distribution networks and/or their regional councils should consider the following points to positively impact public water consumption and perception.

- Every water distribution network should have an accurate model to predict the free chlorine level at any point and any operational conditions.
- The accuracy of the model should be checked and improved frequently by incorporating new knowledge and field observations.
- A systematic programme should be implemented to maintain public water outlets.

Citizens in a general capacity, e.g. individuals, parents, should consider the following point before consumption of water from a public outlet.

- If you think a water outlet has not been used for some time, it is recommended to waste the first flush (1–2 minutes), before drinking, or filling up a reusable container.

There are a number of similarities between water distribution networks investigated in this study and operated in developing countries, such as chlorination to disinfect water, comparatively low connection density and limited skilled labours to operate networks. The results of this paper highlight the importance of free chlorine modelling in water distribution networks operated in developing countries. If the water leakages and possible contaminations are comparatively higher in a network, a safe free chlorine level throughout the network should be well maintained.

CONCLUSION

Analytical results of more than 11,000 water samples collected from various water distribution networks suggest that drinking water quality in regional NSW is generally good. Maintaining the required free chlorine level in entire distribution networks is identified as the major challenge in regional water supply systems. Water taps installed in public places are rarely used by the regional population, and most of them failed to meet drinking water quality guidelines. Almost all water bubblers found in this study were made of stainless steel. The surface temperature of steel bubblers in summer may reach more than 50 °C, which makes them unpopular among users, particularly among school children. Basic modifications in design and operational procedure could easily solve most issues in regional drinking water systems.

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