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

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Abstract: As drinking water quality is directly related to health, it is important for water utilities to monitor and assess the quality of their drinking water supply. New South Wales Health has maintained a comprehensive drinking water monitoring program for non-metropolitan areas of the state since 2001. Over 214,000 chemical and physical test results from 322 public drinking water supply systems were recorded in the monitoring database from 2001 to 2007. The study presents the analysis of the chemical characteristics of drinking water from this most complete regional drinking water database in Australia.

We assessed the chemical quality of drinking water and examined the association between the compliance of chemical characteristics and explanatory factors. We defined a supply system as non-compliant if the 95th percentile of any health-related characteristic was greater than the guideline value from the *Australian Drinking Water Guidelines 2004* over the seven year assessing period. The explanatory factors included the supply system population, treatment, water source and other related characteristics. Generalized linear models were applied with the appropriate model goodness-of-fit test and diagnostics.

Over seven years, 80% of supply systems were compliant with guideline values for all health related characteristics. The most frequent non-compliant characteristics were lead, antimony, nickel and manganese. A number of these non-compliant characteristics could arise from the materials used in pluming. Further investigation is needed to confirm the source of some non-compliant characteristics. We concluded that compliance of supply systems was significantly correlated with population (odds ratio 0.82 for each 1000 increase with 95% CI: 0.69-0.97), and inversely correlated with median total hardness (odds ratio 1.06 for 20 mg/L increase with 95% CI: 1.01-1.11). The marginal effect of a change with the interaction between treatment and turbidity, and other important factors affecting compliance were also considered.

The results from this study provide a better understanding of the factors associated with chemical compliance of drinking water, including the benefit of particle removal (and turbidity reduction) in improving the chemical quality of drinking water. In particular, the findings of this study should prompt managers of water utilities to examine carefully the water quality data available to them. Water utilities should review their data on source water and drinking water to determine whether there is a need to optimise or add treatment processes.

Keywords: *assessment of drinking water quality, chemical compliance, water supply system explanatory factors, generalized linear models (GLMs)*

1. INTRODUCTION

A supply of safe drinking water is essential to every community as it is a basic need for human development, health and well-being. Chemical contamination of drinking water is often considered a lower priority than microbial contamination by regulators, because adverse health effects from chemical contaminations are generally associated with long-term exposures, where the effects from microbial contamination is usually immediate (WHO, 2007). Nonetheless, chemical contamination can affect the taste and appearance of water, lead to community anger, detrimental economic impacts and in some cases serious morbidity (NHMRC, 2004; WHO, 2006; Parvez et al., 2006; Scholz and Cavagnino, 1995; Walker, 1999).

Effective monitoring and comprehensive assessment of public drinking water supply systems are crucial to protect the wellbeing of the public and to allow implementation of a preventive approach to manage drinking-water quality. New South Wales Health (NSW Health) has maintained a comprehensive drinking water monitoring program for regional areas of the State since 2001. Water samples are collected from more than 300 supply systems, which were managed by around 100 water utilities. There are 27 chemical characteristics routinely tested at accredited laboratories in NSW. In cases where guideline values are exceeded, NSW Health Public Health Units work with water utilities to investigate and assess the risk to the community in accordance with established protocols (NSW Health, 2005; Lawrence et al., 2007; Alam et al., 2008; Brodlo et al., 2005).

In this study, we developed a method based on the *Australian Drinking Water Guidelines 2004* (NHMRC, 2004, referred to as the Guidelines) to assess the chemical quality of water supply using this most complete regional drinking water database in Australia. We applied statistical analyses to identify explanatory factors affecting the chemical quality of drinking water at supply system level in regional NSW.

2. THE NSW HEALTH DRINKING WATER MONITORING PROGRAM

Chemical water samples from the NSW Health Drinking Water Monitoring Program collected from 1 January 2001 to 31 December 2007 were analysed for this study. Over these seven years, 322 supply systems submitted 8,126 chemical samples. These supply systems cover all regions of NSW outside the Sydney and Hunter metropolitan areas, and serve a population of nearly 1.7 million people (see Figure 1 for the coverage of the program).

There were a number of different types of treatments applied before the water was distributed to the end users. In this analysis, we focus on particle removal treatments. Only about one third of systems were treated with both physical and chemical particle removal treatments, as shown in Table 1.

Table 1. Particle removal treatments among supply systems.

Particle removal treatment	No. of supply systems	Percentage of all systems
Chemical method only	1	0.3
Physical method only	51	15.8
Both of the above methods	111	34.5
No particle removal treatment	149	46.3
No treatment	10	3.1
Total	322	100.0

The number of samples allocated for each water supply system is based on the minimum sampling frequency recommended in the Guidelines according to the population served and the complexity of the system. Recommended sampling numbers may change over time (NSW Health 2005). The chemical sample allocation is shown in Table 2. Up to 80% of supply systems collect only two samples a year.

Table 2. Basis for allocating chemical sample numbers.

Population served by supply system	Number of supply systems*	% of supply systems	Recommended minimum number of samples per year
< 5000	258	80	2
>= 5000	64	20	12
Total	**322**	**100**	

Test results (214,370 results) were recorded in the NSW Drinking Water Database. The 32 characteristics included in this chemical analysis are grouped into three categories: aesthetic and health-related chemical characteristics, and physical characteristics, according to the Guidelines (Table 3).

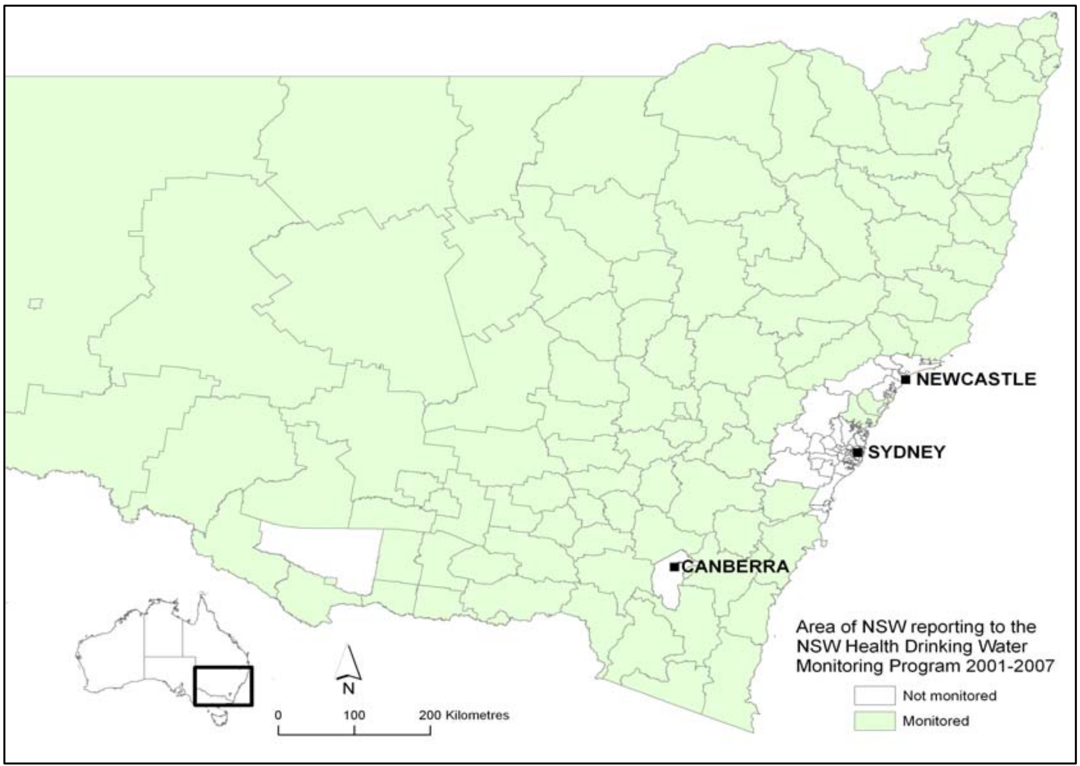

Figure 1. The coverage of NSW Health Drinking Water Monitoring Program.

Table 3. Chemical characteristics tested in the Drinking Water Monitoring Program and their guideline value (NSW Health, 2005; NHMRC, 2004).

Category	**Characteristic**	**Guideline Value mg/L)**	**Category**	**Characteristic**	**Guideline value (mg/L)**
Chemical: Health-related	Antimony	0.003	**Chemical: Aesthetic**	Aluminum	0.2
	Arsenic	0.007		Calcium	n/a[4]
	Barium	0.7		Chloride	250
	Boron	4		Iron	0.1
	Cadmium	0.002		Magnesium	0.3
	Chromium	0.05		Sodium	n/a[4]
	Copper	2		Zinc	180
	Cyanide	0.08	**Physical**	pH	8.5
	Iodide	0.1		Total Dissolved Solids (TDS)	500
	Iodine[1]	n/a[4]			
	Lead	0.5		Total Hardness as CaCO3	200
	Manganese	0.001			
	Mercury	0.05		True Colour	15.0 HU[2]
	Molybdenum	0.02		Turbidity	5.0 NTU[3]
	Nickel	50	**Note:**	1. Iodine is performed as a screening test for iodide. If elevated then test for iodide is performed;	
	Nitrate	3			
	Nitrite	0.01		2. HU: Hazen Unit;	
	Selenium	0.1		3. NTU: nephelometric turbidity unit	
	Silver	500		4. No guideline value	
	Sulfate	0.003			

3. METHOD

3.1. Defining the compliance of the chemical water quality of supply systems

Two problems arose when we analysed the chemical quality of drinking water. First, there were a large number of chemical characteristics (Table 3). Secondly, the majority of supply systems only collected two samples per year. To address these problems, we developed a feasible and comprehensive definition for the compliance of supply systems based on the Guidelines.

In this analysis, we defined a non-compliant system and a non-compliant characteristic of a supply system based on the Guidelines (NHMRC, 2004). A system was defined as a *non-compliant system* if the 95th percentile of *any health-related* characteristics was greater than the guideline value. Any physical and aesthetic chemical characteristic of a supply system was defined as *a non-compliant characteristic* if the upper bound of the 95% confidence interval for the mean of that particular characteristic was less than the guideline value. Given the small number of samples for those supply systems with less than 5000 people, we reviewed the chemical compliance of all supply systems over a seven year period, instead of one-year period which was suggested in the Guideline (NHMRC, 2004).

3.2. Identifying the explanatory factors associated with the compliance of supply systems

Generalized Linear Models (GLMs) were applied with the appropriate model goodness-of-fit test and diagnostics (Hosmer and Lemeshow, 2000). The outcome of interest was the compliance of each supply system for the health related characteristics, as defined above. The explanatory factors include the population size for each supply system, treatment type, including both chemical particle removal (eg coagulation and flocculation) and physical particle removal treatments (eg filtration), water source (including: ground water, surface storage and water course) and physical characteristics listed in Table 3.

We performed univariable and multivariable logistic analyses. We carried out backwards selection to identify the explanatory factors associated with the chemical compliance of the supply systems. The method of fractional polynomials was applied to check the linear assumption of the continuous variables with the logit transformation. The possible combinations of interaction terms were added and assessed in the model after considering relevant literature (NHMRC, 2004; WHO, 2006). The Hosmer-Lemeshow test (c-hat) and the area under the receiver operating characteristic (ROC) curve, i.e. *c*-statistics, were adopted to assess the goodness-of-fit and discrimination of the models.

We also checked the following regression diagnostic statistics due to the deletion of the systems with a covariate pattern: 1) the decrease in the value of the Pearson chi-square statistic; 2) the change in the deviance; 3) the change in the estimated coefficients. The outlying covariate patterns, which caused the large changes of the above diagnostics statistics (greater than four), were deleted from the model to check the influence to the model coefficients and goodness-of-fit. Those influential covariate patterns were deleted from the final model. SAS 9.1 and STATA 10 were used to perform the analysis.

4. RESULTS

Over seven years, 20.5% of supply systems (66/322) had at least one health-related characteristic with 95th percentile test results greater than the guideline values. The majority of these non-compliant supply systems had only one non-compliant health-related characteristic (Table 4). Of the 66 non-compliant supply systems, about half were due to lead (Table 5). Other common non-compliant characteristics included antimony, nickel, manganese, arsenic and copper.

We observe that total hardness was one of the most common non-compliant physical characteristics (Table 6). Among aesthetic characteristics, iron and aluminum were the most frequently non-compliant characteristics.

Table 4. Non-compliant characteristics in supply systems.

No. of non-compliant characteristics	No. of non-compliant supply systems	Percentage of non-compliant systems	Percentage of all systems
1	53	80	16.5
2	10	15	3.1
3	2	3	0.6
4	1	2	0.3
Total	**66**	**100**	**20.5**

Table 5. Non-compliant supply systems by health-related characteristics.

Health-related characteristics	No. of supply systems	Percentage of non-compliant systems	Percentage of all systems
Lead	29	35	9.0
Antimony	12	14	3.7
Nickel	9	11	2.8
Manganese	8	10	2.5
Arsenic	7	8	2.2
Copper	7	8	2.2
Cadmium	3	4	0.9
Iodide	3	4	0.9
Chromium	2	2	0.6
Barium	1	1	0.3
Nitrate	1	1	0.3
Sulfate	1	1	0.3
Total	**83**	**100**	**25.8**

Table 6. Non-compliant physical and aesthetic characteristics among supply systems.

Category	Characteristics	No. of non-compliant systems	Percentage of all systems*
Physical	**Total Hardness as CaCO3**	55	17.2
	pH	46	14.3
	Total Dissolved Solids (TDS)	43	13.4
	Turbidity	42	13.0
	True Colour	17	5.3
Aesthetic	**Iron**	79	24.7
	Aluminum	70	21.9
	Chloride	16	5.0
	Zinc	1	0.3

From the multivariable regression analyses, we identified the following factors that were significantly associated with the compliance of supply systems for health-related characteristics (in Table 7. The model has *C*-statistic 0.78 and C-hat 2.04 with p-value 0.9; both indicate the model provides a good fit and discrimination.). For each 1000 person increase in **supply system population,** the probability of a system being non-compliant for health-related characteristics decreased 18%, (95%CI 3% to 21%). The **median level of total hardness** for all supply systems ranged from 1.3 mg/L to 638 mg/L. We also found that for a 20 mg/L increase in total hardness, the odds of a system being non-compliant increased 6%. The study also found that there is an interaction between **median turbidity** and **particle removal treatment**. When the median turbidity was close to zero, the odds of a system

Table 7. The odds ratios and 95% CI from the final model for system compliance (health-related characteristics).

Parameter	Odds ratio (95% CI)	P-value
Supply system population (every 1000 people increase)	0.82 (0.69, 0.97)	<0.05
Total hardness (every 20 mg/L increase)	1.06 (1.01, 1.11)	<0.05
Treatment (with both chemical and physical particle removal treatment Versus without)	0.15 (0.04, 0.60)	<0.01
Turbidity	1.28 (1.02, 1.61)	<0.05
Interaction between turbidity and treatment	21.28 (1.96, 230.84)	<0.05

Note: *C*-statistic =0.78, C-hat =2.04 with p-value 0.9; both indicate the model provides a good fit and discrimination.

being non-compliant with **both chemical and physical particle removal treatments** decreased 85% compared to those systems without such treatments (95%CI: 40%-96%). The **median turbidity** level ranged from 0.1 to 13.6 NTU between supply systems. Regardless of whether a supply system had both chemical and physical particle removal treatments or not, a one unit (NTU) increase in the system's median turbidity may have seen the odds of being a non-compliant system increase 28% (95%CI for the OR: 1.02-1.61).

5. DISCUSSION

The majority of water supply systems in regional NSW were compliant with the Australian Drinking Water Guidelines (NHMRC, 2004). In considering the findings of this study the derivation of the guideline values needs to be kept in mind. In most cases, guideline values protect against chronic effects of characteristics over an anticipated lifespan of 70 years. Occasional excursions slightly above the guideline value may not represent a health risk. In the cases of copper, nitrate, and sulfate the guideline values are set to protect against potential acute outcomes. In these cases, an excursion above the guideline value may be more likely to result in a health effect.

A number of the non-compliant characteristics, such as lead, antimony, nickel, copper, and chromium, could arise from the materials used in plumbing. These metals might be found in solder (lead and antimony), pipe work (lead, copper), taps (chromium, nickel) and brass and bronze joints and valves (copper, lead) (NHMRC, 2004; WHO and WPC, 2006b). Although these characteristics are likely to arise from the plumbing system, their origin can not be confirmed without information on source water. During the period of the study, one case of elevated nickel was traced to source water (Alam et al., 2008). Where non-compliant characteristics are not elevated in the source water, the water utility would need to consider plumbing materials as a possible source. Further investigation should consider source water and the treated drinking water before it enters household plumbing. Following up actions, such as flushing by householders (as recommended by NSW Health 2004) or possibly additional treatment could help control pluming related problems. Some characteristics are unlikely to come from plumbing fixtures e.g. arsenic, cadmium, iodide, barium, manganese, nitrate and sulfate. These characteristics could be addressed by treatment or change to source water, if the need was indicated by a risk assessment.

The study showed that reducing turbidity or applying both physical and chemical particle removal treatment is effective in improving chemical compliance. Conventional treatment, such as filtration preceded by flocculation/coagulation, helps reduce a number of chemical characteristics, such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc (NHMRC, 2004). Two third of supply systems did not apply both treatments. An improvement in water quality could be expected, where chemical characteristics are elevated in source water, if both physical and chemical particle removal treatments were used.

The population served by a supply system could act as a proxy for the capacity of the community to pay for a well-treated supply and for skilled staff to operate, monitor and manage the system. The study found that the larger the population served by supply systems the lower the risk of being non-compliant for health-related characteristics. This finding cannot be explained by source type, as there is no relationship between source type and population (data not shown).

An interesting finding is that the higher the median total hardness, the more likely the supply system is non-compliant. Total hardness was an indicator for the presence of health-related chemical characteristics. This may reflect the potential for water to cause corrosion as both very soft and very hard water can interact with piping materials (WHO, 2009).

Based on the Guidelines, we developed the methods to evaluate the chemical quality of water supply from regional NSW supply systems over a seven year period. There are limitations in this study including sampling frequency. The majority of supply systems only submitted two samples per year, despite NSW Health's recommendation that water utilities assess risks and where necessary sample more frequently (NSW Health 2005). It is possible that samples are not representative of long-term trends, for example samples taken after heavy rain fall or when the water level was low due to drought. In addition, samples were only taken from locations representative of the supply of consumers. We could not definitively identify the source for non-compliant characteristics without information on their concentration in the source water and after treatment.

There are some issues that could not be controlled for in the study. First, the choice of sampling location might increase the likelihood of a high concentration for the plumbing related characteristics. For example, a tap in a park that is used infrequently may build up higher concentrations of dissolved metals than a more regularly flushed outlet. Secondly, the sampling practice of the water utility officer may also influence the result; whether they flush the tap before collecting the sample as required by NSW Health, as flushing is known to affect the concentration of some metals (Rajaratnam et al., 2002).

The results of this study provide a better understanding of the factors associated with chemical compliance of drinking water in regional NSW. In particular, the findings of this study should prompt managers of water utilities to examine carefully the chemical quality of their drinking water supply and identify opportunities for improvement. Water utilities should review their data on source water and drinking water to determine whether there is a need to optimise or add treatment processes.

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