

Burden of Disease Attributed to Waterborne Transmission of Selected Enteric Pathogens, Australia, 2010

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Abstract. Universal access to safe drinking water is a global priority. To estimate the annual disease burden of campylobacteriosis, nontyphoidal salmonellosis, cryptosporidiosis, giardiasis, and norovirus attributable to waterborne transmission in Australia, we multiplied regional World Health Organization (WHO) estimates of the proportion of cases attributable to waterborne transmission by estimates of all-source disease burden for each study pathogen. Norovirus was attributed as causing the most waterborne disease cases (479,632; 95% uncertainty interval [UI]: 0–1,111,874) followed by giardiasis and campylobacteriosis. The estimated waterborne disability-adjusted life year (DALY) burden for campylobacteriosis (2,004; 95% UI: 0–5,831) was 7-fold greater than other study pathogens and exceeded the WHO guidelines for drinking water quality (1×10^{-6} DALY per person per year) by 90-fold. However, these estimates include disease transmitted via either drinking or recreational water exposure. More precise country-specific and drinking water-specific attribution estimates would better define the health burden from drinking water and inform changes to treatment requirements.

Water is an important source of infectious diseases transmission. The global burden of disease study estimated that in 2015, an unsafe water source resulted in 1.2 million deaths and 71.7 million disability-adjusted life years (DALYs), including 1.1 million deaths and 61.1 million DALYs from diarrheal diseases.¹ The sixth Sustainable Development Goal includes the target to achieve universal and equitable access to safe and affordable drinking water by 2030.² However, in 2015 it was estimated that 56% of the world's population had an unsafe water source, with unsafe water source ranking third as a preventable cause of DALYs in low and low-middle sociodemographic index (SDI) countries.¹ Unsafe water source did not appear in the 10 top-ranked risk factors for high, middle-high, or middle SDI countries. The burden of waterborne disease is not well characterized in high-income countries, but is assumed to be less than in lower income countries.

To ensure access to safe drinking water while recognizing that it is impossible to achieve a zero health risk from consumption of drinking water, the World Health Organization (WHO) Guidelines for Drinking-water Quality recommend use of a microbial health-based target, defining a tolerable burden of disease of $\leq 1.0 \times 10^{-6}$ DALY per person per year for each category of waterborne pathogen (bacteria, viruses, and protozoa) from drinking water as an upper limit.³ These guidelines also recognize that less stringent targets might be realistic and consistent with the goals of providing safe drinking water in some settings. This health-based target can be used to determine the treatment requirements for drinking water supplies in a variety of settings. To date, Canada is the only country to adopt these targets in drinking water guidelines^{4,5}; however, Australia seems likely to soon follow.⁶ The Canadian and draft Australian Guidelines set DALY targets and identify mechanisms for individual water

supplies to meet these targets. One way to understand the local DALY-burden of pathogens attributed to drinking water is to combine knowledge of pathogen concentration in source water, log-reduction of pathogens achieved through water treatment, average water consumption, likelihood of infection when exposed to pathogens, likelihood of illness in the setting of infection, and average burden of a disease case (DALY/case) to estimate the DALY-burden attributable to drinking water. A likely approach to the assessment of drinking water safety would be to use this methodology to determine the percentage of supplies that comply with the target, supported by epidemiological studies including assessments of waterborne disease outbreaks. An alternate approach relevant at the national or jurisdictional level is to estimate the proportion of all-source cases for relevant pathogens that are transmitted through drinking water using disease surveillance and other epidemiological data. Although attribution studies commonly focus on foodborne transmission, some have included attribution of disease to waterborne transmission. In particular, a recent WHO study of the global burden of foodborne disease in 2010 based on expert elicitation reported several transmission routes including water for 14 subregions of the world.⁷

To prepare for the potential move to a DALY-based target for the Australian Drinking Water Guidelines, the all-source DALY burden of six potentially waterborne enteric pathogens was estimated for Australia in 2010.⁸ In that study, we selected the two most common pathogens from each pathogen group relevant to waterborne transmission: bacterial (campylobacteriosis and salmonellosis), viral (norovirus and rotavirus), and protozoal (giardiasis and cryptosporidiosis). Five of these pathogens (excluding rotavirus) were included in the recent WHO attribution study described earlier.

To estimate the disease burden attributable to waterborne transmission in Australia in 2010, for each of the study pathogens (campylobacteriosis, nontyphoidal salmonellosis, cryptosporidiosis, giardiasis, and norovirus) we multiplied our published point estimates of all-source disease burden in Australia (Table 1) by regional WHO estimates of the pathogen-specific proportion of cases attributable to waterborne transmission in 2010 (point estimates and 95%

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TABLE 1
All-source annual burden of selected gastrointestinal pathogens, Australia, 2010⁸

	Cases	Deaths	DALY
Campylobacteriosis	774,003	52	18,222
Salmonellosis	71,255	90	3,856
Norovirus	2,180,145	17	1,109
Giardiasis	614,740	0	967
Cryptosporidiosis	195,495	0	333

DALY = disability-adjusted life year. Australia's population in 2010 was approximately 22.3 million.

uncertainty intervals [UIs]; Table 2).^{7,8} The all-source burden of disease estimates for study pathogens included number of cases, number of deaths, and DALYs. Postinfectious sequelae were included in the DALY calculations for campylobacteriosis (irritable bowel syndrome [IBS], reactive arthritis [ReA], and Guillain-Barré syndrome) and salmonellosis (IBS and ReA) but not for other pathogens. The regional WHO attribution estimates were for the Western Pacific Region Stratum A (WPR-A) and included Australia, Brunei, Japan, New Zealand, and Singapore. Attribution was made at the point of human exposure; therefore, disease caused by consumption of food that had contact with contaminated water was attributed to foodborne transmission. Waterborne transmission included both drinking water and recreational water sources. The percentage of cases attributed to waterborne transmission ranged from 1% for salmonellosis to 39% for cryptosporidiosis (Table 2). The 95% UIs for waterborne transmission were wide, with the lower limit of the 95% UIs at 0% for campylobacteriosis, salmonellosis, and norovirus; 1% for giardiasis; and 3% for cryptosporidiosis.

As well as causing the greatest number of all-source disease cases in Australia in 2010 (Table 1), norovirus was attributed as causing the most waterborne disease cases (479,632 [0–1.1 million] waterborne cases), followed by giardiasis (178,275 [6,147–418,023]) and campylobacteriosis (85,140 [0–247,681]; Table 2). Deaths were attributed to waterborne transmission of campylobacteriosis (six [0–17]), norovirus (four [0–9]), and salmonellosis (one [0–20]). The estimated DALY burden of waterborne campylobacteriosis (2,004 [0–5,831]) was 7-fold higher than for any other study pathogen. The DALY burden of waterborne giardiasis, norovirus, and cryptosporidiosis in Australia in 2010 ranged from 130 to 280 DALYs, whereas waterborne salmonellosis caused low DALY burden (39 DALYs [0–848]). The DALY burden attributed to waterborne transmission exceeded the WHO recommendation for drinking water for

all pathogens; however, these estimates include both drinking water and recreational water sources. The WHO drinking water target of $\leq 1 \times 10^{-6}$ DALY per person per year would be met if the proportion of waterborne cases attributed to drinking water exposure was $< 58\%$ for salmonellosis and as low as $< 1\%$ for campylobacteriosis (Table 2).

Australia ranks the second on the United Nation's Human Development Index,⁹ confirming it as one of the most privileged countries in the world. However, these results indicate potential waterborne transmission of gastrointestinal pathogens in Australia, and occasional waterborne outbreaks have been reported.¹⁰ The cases attributed to waterborne transmission included both drinking water and recreational water exposure meaning the WHO drinking water target cannot be directly applied to our DALY burden estimates for waterborne disease. A recent Canadian study estimated the proportion of waterborne cases attributable to recreational water exposure was 22.0% for campylobacteriosis, 18.7% for cryptosporidiosis, and 32.1% for giardiasis cases.¹¹ In contrast, of the 54 "waterborne" or "suspected waterborne" gastroenteritis outbreaks reported to Australia's OzFoodNet from 2001 to 2007 (all attributed to pathogens included in this study), 78% were attributed to recreational water and 19% to drinking water.¹⁰ Significantly, six of the 10 drinking water outbreaks identified occurred at camps and one in a public rural bore water supply; these did not involve public reticulated water supplies. The large urban water supplies providing water to a high proportion of Australians recorded no outbreaks from 2000 to 2007. While acknowledging that many waterborne cases will be recreational water associated, the WHO DALY target would only be met if $< 1\%$ of our estimated waterborne campylobacteriosis cases were attributed to drinking water.

The disease burden estimates used in this manuscript were developed specifically for Australia and were based on the recent global burden of disease study.⁸ However, these DALY/case estimates were lower than in a study from the Netherlands (23.5 versus 41 DALY/1,000 campylobacteriosis cases),¹² likely due to a higher estimated case fatality rate for campylobacteriosis in the study from the Netherlands. This indicates we might have overestimated the number of drinking water-associated campylobacteriosis cases tolerated within the WHO DALY target. As attribution was made at point of human exposure,⁷ disease caused by food that had contact with contaminated water was attributed to foodborne transmission. If these cases were instead attributed to waterborne transmission, the estimated burden of waterborne disease would be greater. Conversely, the estimated

TABLE 2
Annual disease burden of study pathogens attributable to waterborne transmission, Australia, 2010

	Waterborne proportion,* median (95% uncertainty)	Cases	Deaths	DALYs	10^{-6} DALYs per person per year†	Waterborne cases that can be drinking-water related to meet the WHO DALY target (%)‡
Campylobacteriosis	11% (0–32)	85,140 (0–247,681)	6 (0–17)	2,004 (0–5,831)	90 (0–261)	1
Salmonellosis	1% (0–22)	713 (0–15,676)	1 (0–20)	39 (0–848)	2 (0–38)	58
Norovirus	22% (0–51)	479,632 (0–1,111,874)	4 (0–9)	244 (0–566)	11 (0–25)	9
Giardiasis	29% (1–68)	178,275 (6,147–418,023)	0 (0–0)	280 (10–658)	13 (0–29)	8
Cryptosporidiosis	39% (3–72)	76,243 (5,865–140,756)	0 (0–0)	130 (10–240)	6 (0–11)	17

DALY = disability-adjusted life year; WHO = World Health Organization. Burden presented as number (95% uncertainty interval).

* Percent of all-source gastrointestinal cases attributed to waterborne transmission, by study pathogen; estimates for Western Pacific Region Stratum A (WPR-A), which includes Australia, Brunei, Japan, New Zealand, and Singapore.

† WHO target $\leq 1 \times 10^{-6}$ DALY per person per year from drinking water; these waterborne disease burden estimates include both drinking and recreation water sources.

number of gastroenteritis and IBS cases we used exceeded those of another contemporary Australian study,^{13,14} indicating we could have overestimated the disease burden of study pathogens.

The WHO attribution estimates used were at the regional and not country level and it is likely there are differences in disease epidemiology, including disease incidence and the proportion of all cases that are waterborne in Australia compared with other countries included in the WPR-A estimates. For example, in 2014 notification incidence for campylobacteriosis was lower in Singapore (8/100,000) than in Australia (125) and New Zealand (150).^{15–17} Salmonellosis notification incidence in 2014 differed in New Zealand (21/100,000), compared with Singapore (35) and Australia (70). Of all-source cases notified in New Zealand in 2014, 8% of campylobacteriosis cases, 13% of giardiasis cases, and 21% of cryptosporidiosis cases had untreated drinking water as a risk factor¹⁸; recreational water contact was also commonly reported among notified cases.¹⁷

Along with the other studies, the WHO attribution study was focused on foodborne disease. The waterborne estimates were imprecise with wide uncertainty intervals, reflecting the considerable variability in point estimates, and width of interval estimates of foodborne proportion noted in different national studies.¹⁹ An expert elicitation study of foodborne pathogens in Australia circa 2010 included estimates of waterborne transmission (recreational and drinking water) for three pathogens included in our study, with a lower estimated waterborne proportion for *Campylobacter* (median: 6% [95% credible interval: 2–10%]) and norovirus (3% [0–10%]) but higher for nontyphoidal *Salmonella* (5% [1–10%]) compared with the WPR-A estimates from the WHO study (Table 3).^{7,20} Using these alternate waterborne proportion estimates for Australia, the WHO drinking water target of 1×10^{-6} DALYs per person per year would be met if 2% of campylobacteriosis cases attributed to waterborne transmission in Australia were due to drinking water (similar to our conclusions using the WPR-A estimates from the WHO study), 12% of salmonellosis cases, and 67% of norovirus cases.

Even in a high-income country like Australia, it is important to consider whether improvements in water quality could lessen the burden of disease from study pathogens. More precise attribution estimates for waterborne transmission are required, and these should be country specific and exposure specific (drinking, recreation, food contaminated with fecally polluted water). Although it is unlikely that the “attribution” based estimates presented here would be applied in the day-to-day management of drinking water supplies by individual water suppliers, they represent the only available estimate of the national disease burden attributed to water. Periodic assessments using this approach coupled with more precise country-specific and drinking water-specific attribution estimates could provide a national overview of disease burden associated with drinking water and success in reaching national and WHO drinking water safety targets. Furthermore, such studies could be used to benchmark drinking water-associated disease burden in Australia against similarly developed countries. Such data would guide decisions regarding the extent of water treatment required to meet the WHO targets for drinking-water quality in Australia.

TABLE 3
Comparison of the estimated annual disease burden of *Campylobacter*, *Salmonella*, and norovirus attributable to waterborne transmission, Australia, 2010, using waterborne proportion estimates from the WPR-A⁷ and Australia²⁰

	<i>Campylobacter</i>		<i>Salmonella</i>		Norovirus	
	WPR-A	Australia	WPR-A	Australia	WPR-A	Australia
% Waterborne*	11% (0–32%)	6% (2–10%)	1% (0–22%)	5% (1–10%)	22% (0–51%)	3% (0–10%)
Cases	85,140 (0–247,681)	46,440 (15,480–77,400)	713 (0–15,676)	3,563 (1,425–7,126)	479,632 (0–1,111,874)	65,404 (43,603–218,015)
Deaths	6 (0–17)	3 (1–5)	1 (0–20)	5 (2–9)	4 (0–9)	1 (0–2)
DALYs	2,004 (0–5,831)	1,093 (364–1,822)	39 (0–848)	193 (77–386)	244 (0–566)	33 (33–111)
10^{-6} DALY per person per year	90 (0–261)	49 (16–82)	2 (0–38)	9 (4–17)	11 (0–25)	1 (1–5)
Waterborne cases that can be drinking-water related to meet the WHO DALY target†	1%	2%	58%	12%	9%	67%

DALY = disability-adjusted life year; WHO = World Health Organization; WPR-A = Western Pacific Region Stratum A. WPR-A includes Australia, Brunei, Japan, New Zealand, and Singapore.

*Percent of all-source gastrointestinal cases attributed to waterborne transmission.

†WHO target $\leq 1 \times 10^{-6}$ DALY per person per year from drinking water; these waterborne disease burden estimates include both drinking and recreation water sources.

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