

Where's the pump? Associating sporadic enteric disease with drinking water using a geographic information system, in British Columbia, Canada, 1996–2005

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ABSTRACT

We investigated whether risk of sporadic enteric disease differs by drinking water source and type using surveillance data and a geographic information system. We performed a cross-sectional analysis, at the individual level, that compared reported cases of enteric disease with drinking water source (surface or ground water) and type (municipal or private). We mapped 814 cases of campylobacteriosis, cryptosporidiosis, giardiasis, salmonellosis and verotoxigenic *Escherichia coli* infection, in a region of British Columbia, Canada, from 1996 to 2005, and determined the water source and type for each case's residence. Over the 10-year period, the risk of disease was 5.2 times higher for individuals living on land parcels serviced by private wells and 2.3 times higher for individuals living on land parcels serviced by the municipal surface/ground water mixed system, than the municipal ground water system. Rates of sporadic enteric disease potentially differ by drinking water source and type. Geographic information system technology and surveillance data are accessible to local public health authorities and used together are an efficient and affordable way to assess the role of drinking water in sporadic enteric disease.

Key words | enteric disease, geographic information system, water

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INTRODUCTION

The provision of clean drinking water has long been recognized as a fundamental priority for ensuring public health (WHO 2004). Even in developed countries, waterborne disease continues to be a serious public health concern (BC Provincial Health Officer 2001). Although waterborne outbreaks are well documented (MacKenzie *et al.* 1993; Schuster *et al.* 2005), little is known about sporadic cases of waterborne disease. Risk factors for sporadic cases are difficult to assess as enteric infections are greatly under-reported (MacDougall *et al.* 2008), people consume water from a variety of sources and exposure to drinking water is continuous (Jones *et al.* 2006). Additionally, public health

follow-up for confirmed cases of illness differs by pathogen, and drinking water source is not always determined (Flint *et al.* 2004). Pathogens associated with sporadic waterborne illness include *Campylobacter* (Nygard *et al.* 2004; Carrique-Mas *et al.* 2005), verotoxigenic *Escherichia coli* (Chalmers *et al.* 2000), *Salmonella* (Kapperud *et al.* 1998), *Cryptosporidium* and *Giardia* (Isaac-Renton *et al.* 1999).

A 2005 workshop entitled 'Estimating Waterborne Disease Risks in the United States' concluded that there remain key data and method gaps to estimate endemic enteric disease attributed to drinking water (Craun & Calderon 2006). An important gap is a lack of knowledge

doi: 10.2166/wh.2009.108

on endemic waterborne risks associated with wells and with ground water. Traditionally, such risks would be evaluated using large, resource-intense cohort studies. However, newer methods such as geographic information systems (GIS) enable researchers to evaluate the association between disease and spatial factors such as drinking water sources (Barcellos & Sabroza 2000; Dangendorf *et al.* 2002; Nygard *et al.* 2004). Dangendorf *et al.* (2002) found that using a GIS revealed spatial variations in the incidence of diarrhoeal illness in Germany explained by the amount of ground water consumed and differences in water treatment. Miller (2007) outlined how local health departments can use a GIS to monitor and protect drinking water systems.

In the present study, we undertook a cross-sectional analysis at the individual level to assess whether the risk of sporadic enteric disease differed by drinking water source (surface or ground water) and type (municipal or private) using surveillance data and a GIS. We were additionally interested in assessing whether this methodology was efficient, practical, affordable and well received, and thus of potential use by municipal governments.

METHODS

Our study took place in Community A, a 307 km² region located within Greater Vancouver, British Columbia, Canada (Statistics Canada 2006). Of the community's 97,000 residents (Statistics Canada 2006), 63% relied on a mix of municipal surface water and municipal ground water for their drinking water, 19% were served by a municipal ground water system only, and 18% relied on ground water from private wells (Antigone Dixon-Warren, ground water specialist, written communication, June 2006). These percentages remained essentially constant from 1996 to 2005. Municipal surface water is treated by chlorination and ozonation, municipal ground water is chlorinated and both are tested according to provincial guidelines (Province of BC 2003). Ground water from private wells is mostly untreated and untested (Antigone Dixon-Warren, ground water specialist, written communication, June 2006).

In BC, all laboratory-confirmed cases of potentially waterborne disease are reportable by law through an electronic reporting system (the integrated Public Health

Information System or iPHIS). For the period 1996–2005, we included all laboratory-confirmed cases of campylobacteriosis, cryptosporidiosis, giardiasis, salmonellosis and verotoxigenic *E. coli* infection (VTEC) with an address in Community A at the time of disease. Missing addresses were found from a registry of BC residents by using a combination of cases' provincial health number (a unique identifier provided at birth), name and birth date. Cases reporting more than one illness during the study period were included as two separate cases.

Cases were geocoded by street address in ArcGIS 8.2 (Environmental Systems Research Institute, Redlands, California) using a street network reference file of BC roads (CanMap Streetfiles V7.0, S dmtispatial Inc., Markham, Ontario) and were mapped according to the residence they lived in at the time of reported illness. Cases plotted more than 25 m outside of the Community A's boundaries were excluded.

Exposure data collected by public health officials, available from the local health authority, were reviewed to exclude outbreak and non-locally acquired cases. *Salmonella* cases with travel related serotypes (*S. typhi* and *S. paratyphi*) were excluded, as were all cases that were known to have travelled for their entire incubation period. There were no known outbreaks in Community A during the study period. Of the few cases that lived in the same household, we could not determine whether exposure was primary or secondary and all cases remained in our analysis. Exposure data were insufficient to exclude potentially non-waterborne, locally acquired cases.

Land parcel-specific drinking water data for Community A were obtained from municipal, provincial and federal government and local health authority data and from environmental assessments commissioned by the community. Every land parcel on the map contained all water source information for that residence, by year. We assigned each land parcel to one of three water systems: municipal mixed (surface and ground) water, municipal ground water, or private well water, based on the year of reported disease. Cases were spatially joined to the nearest land parcel using the join function in ArcGIS 8.2, and matched to the appropriate water system.

Relevant disease surveillance and drinking water information for each case were exported into SPSS®

v.14.0 for descriptive analysis. The number of people on each type of water system was obtained (Antigone Dixon-Warren, personal communication, June 2006) by multiplying the yearly population by the percentage of people on each water system (63%, 19% and 18% for municipal mixed water, municipal ground water and private wells, respectively), and annual incidence rates by illness and by water system were calculated. Rate and confidence interval calculations were performed using a calculator provided by the Pennsylvania Department of Health (2006) in MS Excel®. Risk ratios and 95% confidence intervals were calculated for each system using Statpages, 6th edition in Javastat (Bernard 2006).

This study was reviewed by the Simon Fraser University Research Ethics Board and approved on 5 May 2006.

RESULTS

We identified 957 cases of campylobacteriosis, cryptosporidiosis, VTEC, giardiasis and salmonellosis residing in Community A between 1 January 1996 and 31 December 2005. Following non-locally acquired case exclusion, 840 cases remained for analysis. Of the 840 cases, 814 were successfully geocoded and a drinking water system was identified for that address of residence (Figure 1), representing 797 individual people (17 people reported two episodes of disease over the study period).

Of the original 840 cases, 461 cases (54.9%) were male. The age range was 0–96 years (mean = 33 years, median = 33 years).

The age distribution between the populations on the three different water systems were significantly different (P -value < 0.001 by 2-tailed chi-square test using StatXact version 6.2.0). From the census data it appeared that the youngest population was that supplied by municipal mixed water and the oldest population was on private wells (data not shown) (Statistics Canada 2006).

Campylobacteriosis cases made up 57% of total cases ($n = 479$). Ten year average rates by disease were highest for campylobacteriosis (52 per 100,000), followed by salmonellosis (16 per 100,000), giardiasis (14 per 100,000), VTEC infection (6 per 100,000) and cryptosporidiosis (5 per 100,000).

For all five diseases, rates were highest among individuals living on land parcels serviced by private wells, followed by individuals living on land parcels serviced by the municipal mixed water system (Table 1). Risk of disease for individuals serviced by private wells was significantly higher than for individuals serviced by the municipal ground water system for all ten years studied (Table 2). Risk of disease for individuals on the municipal mixed water system was significantly higher than individuals on the municipal ground water system for the years 1997, 2002 and 2003. Ten-year average risk ratios show that risk of disease was 5.2 times higher for individuals serviced by private wells, and 2.3 times higher for individuals serviced by the municipal mixed water system, than individuals on the municipal ground water system. When campylobacteriosis cases were analysed independently, risk of disease was 8.1 times higher for individuals on private wells and 3.4 times higher for cases on the municipal mixed water system, than for cases on the municipal ground water system. Ten-year average risk ratios for the other four diseases combined (cryptosporidiosis, giardiasis, salmonellosis and VTEC), showed that risk was 4.5 times higher for individuals living on land parcels serviced by private wells and 1.9 times higher for individuals living on land parcels serviced by the municipal mixed water system, than for individuals on the municipal ground water system.

When the rates of the two municipal systems were combined, rates were significantly higher for individuals living on land parcels serviced by private wells than by the municipal systems for all ten years except 2001 (ten year average RR = 2.7) (Figure 2).

DISCUSSION

Using epidemiological and environmental data, and GIS-based analysis, we identified a potential association between drinking water source and sporadic cases of enteric disease. This relationship was constant over the ten-year time period of the study and by disease type. To our knowledge, this is the first time a GIS-based approach to examine sporadic cases of enteric disease using residence-specific drinking water system data has been attempted.

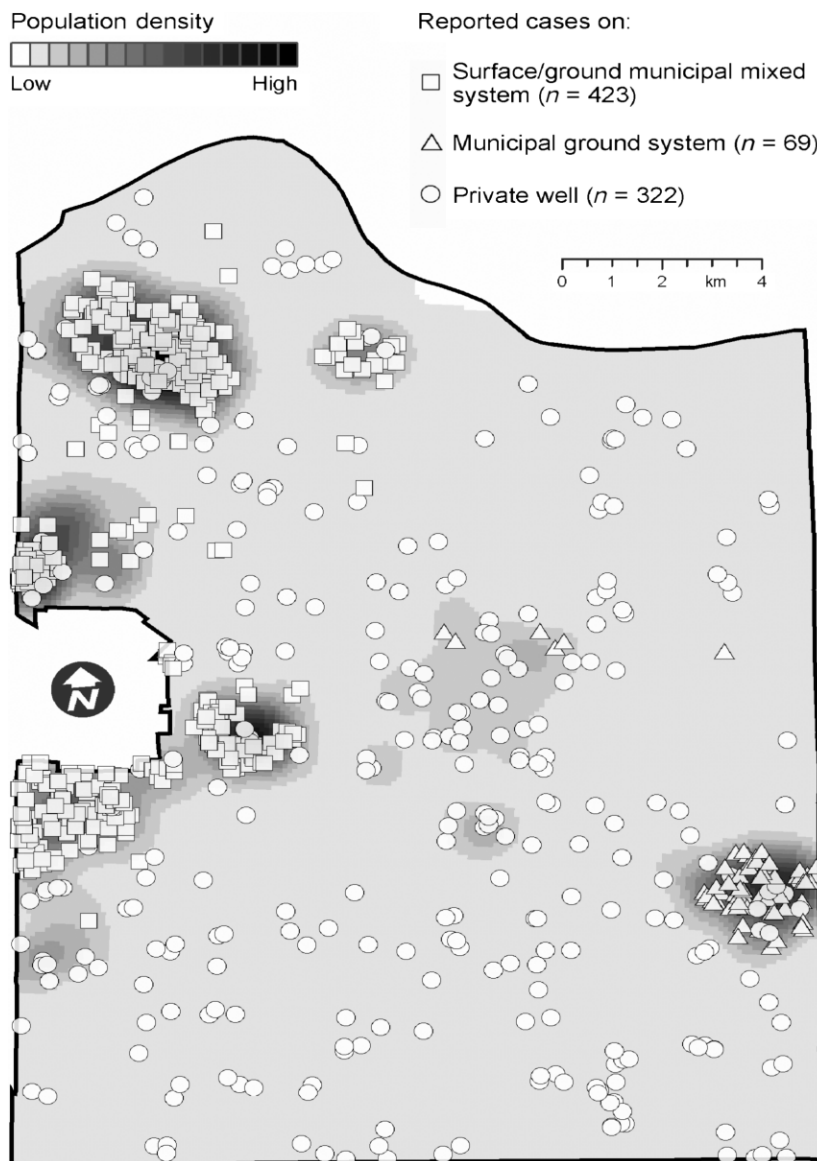


Figure 1 | Cases of campylobacteriosis, cryptosporidiosis, giardiasis, salmonellosis and VTEC in a region of British Columbia, Canada, 1996–2005, by water source (mapped cases have been randomly offset and some have been removed to protect confidentiality).

Our findings provide evidence that people who live on land serviced by private wells may be at higher risk of enteric diseases. This could be due to the proximity of wells to livestock, shallow wells and/or untreated well water (Barwick *et al.* 2000; Clark *et al.* 2003; Simpson 2004). Community A has more farms than any other municipality in BC (Statistics Canada 2001a). Dairy, poultry, beef, swine and sheep farming are key agricultural activities. Poultry and cattle are known reservoirs for all of the pathogenic

organisms studied here (Heymann 2004). Water contamination from agricultural sources can pose significant health risks to residents who draw untreated water from private wells in agricultural areas (Ritter *et al.* 2002). Deteriorated and/or poorly constructed wells are especially susceptible to contamination, via surface runoff or ground water (Ritter *et al.* 2002). Precipitation events can cause animal fecal matter to flow into wells, as was the case for the *E. coli* and *Campylobacter* outbreaks in Walkerton, Canada

Table 1 | Average rates of illness per 100,000 population by water system in Community A, British Columbia, Canada, 1996–2005

Disease	Municipal ground	Municipal mixed	Private well	Total average*
Campylobacteriosis	17	47	105	52
Cryptosporidiosis	2	5	10	5
VTEC	2	6	9	6
Giardiasis	7	11	29	14
Salmonellosis	10	12	31	16
Total average	8	16	37	

*Total average values were calculated from raw data, so differences between row/column averages and total averages is due to rounding.
VTEC = verotoxigenic *E. coli*.

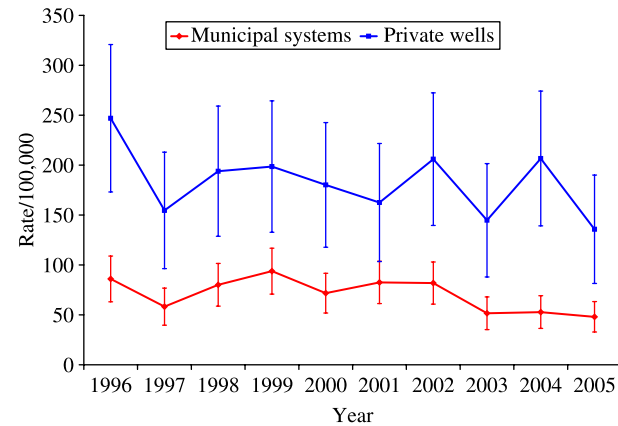
(Clark *et al.* 2003). Very few private wells in Community A were tested or disinfected and some were shallow (less than 15 m), with cracked well rings and in close proximity to animals (Dean Scovill, Environmental Health Officer, personal communication, June 2006).

Our results suggest a risk gradient, whereby untreated water poses a higher risk of disease than treated water, and disinfected but unfiltered surface water poses a higher risk than treated ground water. Other studies support this. Odoi *et al.* (2004) found higher rates of giardiasis in consumers of treated surface water than treated ground water. Although surface water is more susceptible to contamination than ground water (from livestock and other sources), if ground

Table 2 | Risk ratios comparing the municipal mix and private well systems with the municipal ground system in Community A, British Columbia, Canada, 1996–2005

Year	Municipal ground	Municipal mixed RR (95% CI)	Private well RR (95% CI)
1996	Ref	1.60 (0.82–3.14)	4.13 (2.11–8.12)*
1997	Ref	4.09 (1.34–12.53)*	8.73 (2.82–27.05)*
1998	Ref	1.69 (0.84–3.42)	3.68 (1.79–7.55)*
1999	Ref	1.82 (0.94–3.54)	3.42 (1.72–6.81)*
2000	Ref	1.73 (0.83–3.62)	3.89 (1.83–8.30)*
2001	Ref	2.05 (0.99–4.25)	3.52 (1.64–7.57)*
2002	Ref	3.46 (1.42–8.40)*	7.18 (2.91–17.71)*
2003	Ref	3.69 (1.2–11.31)*	8.54 (2.75–26.60)*
2004	Ref	1.46 (0.67–3.24)	5.30 (2.41–11.66)*
2005	Ref	1.59 (0.68–3.71)	4.11 (1.73–9.79)*
Average		2.32	5.25

*Significant at $\alpha = 0.05$.

**Figure 2** | Incidence rates and 95% confidence intervals of total disease (campylobacteriosis, cryptosporidiosis, giardiasis, salmonellosis and VTEC) for combined municipal systems and private wells in Community A, British Columbia, Canada, 1996–2005.

water is untreated, even small amounts of contamination can lead to infection (Nygard *et al.* 2004).

The observed trends are largely driven by campylobacteriosis, as it accounted for 57% of all cases in our study. A 2004 Quebec case-control study found that over 50% of campylobacteriosis cases were due to environmental exposures, namely drinking water (Michaud *et al.* 2004). Private wells were found to be a risk factor for contracting campylobacteriosis by Michaud *et al.* (2004) and Carrique-Mas *et al.* (2005). Additionally, Nygard *et al.* (2004), using GIS-based analyses in their epidemiological investigation, found that rates of campylobacteriosis were positively associated with ruminant density and partly attributed this finding to contamination of private well water. Illness rates by water system for the other four diseases showed the same trend as campylobacteriosis, although the rates were based on a smaller number of cases.

As most private well users live in rural areas (Simpson 2004), it is possible that the observed risk differences were due, in part, to urban/rural differences. Direct animal contact, consumption of different foods and/or different food handling practices could lead to different exposure risks in rural communities. Exposure data was insufficient to control for these factors.

As most waterborne disease usually affects the very young and perhaps the young adult group at highest frequencies, the differential age distribution in the drinking water systems should not have contributed to overestimating

the difference in risk of sporadic enteric disease between municipal and private well drinking water.

Socioeconomic status (SES) could account for some of the observed differences, as lower SES is often associated with higher rates of illness (Auger *et al.* 2004). However, this was not likely to be the case in our study; the population on the municipal ground water system had an annual per capita family income of CAD\$15,000 less than the population on the municipal mixed water system (Statistics Canada 2001b). Whether these aggregated incomes hide individuals of lower SES in a higher SES area is unknown. Annual income for the population on private wells could not be determined from statistical profiles.

As cases were not always matched to the proper land parcel, the water system matched to a case was compared with the water system of the land parcel with the same address as the case. Of the 60 cases chosen at random, four were misclassified, for an error rate of 6.7%. These four appeared to be randomly misclassified (the cases were geocoded to point locations that, by chance, were closer to land parcels with different water systems). Therefore we do not feel such misclassification biased the results.

We used the type of water system feeding a residence as a proxy for an individual's water consumption. This may not adequately reflect each case's drinking water exposure. Individuals may consume water in other locales such as work or school, drink bottled water, or have point-of-use treatment such as filters (Jones *et al.* 2006). However, as King *et al.* (2004) and Jones *et al.* (2006) report, this type of non-differential misclassification would decrease the strength of the associations observed by bringing the risk ratios closer to one (no association). We potentially improved upon the mapping process used by Jones *et al.* (2006) by using street addresses instead of postal codes and by using residence-specific water information. Further, using individual data minimizes the ecological fallacy present in many environmental studies by mitigating the uncertainty of applying population level data to individuals.

CONCLUSION

Based on our findings, we emphasize the importance of adequate private well construction and maintenance,

including testing and treatment. A programme currently exists in Community A to educate well owners and to help them properly maintain and test their wells. If successful, this programme could be a model for similar communities.

Future studies could strengthen the potential association observed in our study by better quantifying an individual's drinking water exposure and by controlling for direct animal contact or differences in food practices.

Finally, we stress the usefulness and efficiency of using a GIS to estimate population level risk factors for sporadic cases of enteric disease. The information gathered can help public health officials identify drinking water systems at higher risk and prevent waterborne disease. Such analytic capacity will become critical in coming years as more water-stressed communities face shortages due to climate change (Greer *et al.* 2008). This problem will be particularly significant for those communities vulnerable to restricted flow related to climate, such as snowmelt dominated runoff sources (Barnet *et al.* 2005).

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First received 4 September 2008; accepted in revised form 15 March 2009. Available online July 2009