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Drinking water quality and hospital admissions of elderly people for gastrointestinal illness in Eastern Massachusetts, 1998–2008

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ABSTRACT

We used a Poisson regression to compare daily hospital admissions of elderly people for acute gastrointestinal illness in Boston against daily variations in drinking water quality over an 11-year period, controlling for weather, seasonality and time trends. The Massachusetts Water Resources Authority (MWRA), which provides non-filtered water to 1.5 million people in the greater Boston area, changed its disinfection method from chlorination to ozonation during the study period so we were also able to evaluate changes in risk associated with the change in disinfection method. Other available water quality data from the MWRA included turbidity, fecal coliforms, UV-absorbance, and planktonic algae and cyanobacteriae concentrations. Daily weather, rainfall data and water temperature were also available. Low water temperature, increases in turbidity and, to a lesser extent, in fecal coliform and cyanobacteriae were associated with a higher risk of hospital admissions, while the shift from chlorination to ozonation has possibly reduced the health risk.

The MWRA complied with US drinking water regulations throughout the study period.

1. Introduction

Microbial contamination of drinking water has long been recognized as a source of acute gastrointestinal illness (AGII). To protect against this, multi-tiered approaches involving combinations of source water protection, filtration, disinfection and residual disinfection have been used. The Massachusetts Water Resources Authority (MWRA) has pursued a policy of protecting its pristine upland water supply source for over a century, which combined with chemical disinfection serves to protect the water against fecal pathogens. The MWRA does not filter its drinking water. In August 2005, the MWRA changed its primary disinfection method from chlorination to ozonation, to better address *Cryptosporidium* spp.

Using 11 years of Medicare data, we examined the relationship between daily counts of admissions of elderly residents of MWRA-served communities in Eastern Massachusetts to local hospitals for AGII and variability in MWRA water quality, including the 2005 disinfection change. The MWRA has remained in compliance with federal drinking water regulations during the study period.

The suspended particles that cause the cloudiness we call turbidity in water are composed of a variety of biological and inorganic substances, including from sewage, organo-mineral particles from surface runoff, algae, precipitated limestone

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particles, etc; most are benign, but some can shelter pathogens. Consequently, turbidity has served as a proxy measure for water quality for over a century.

Time series studies (TSS) have proven successful in examining the role of drinking water turbidity in endemic AGII for water systems meeting federal standards, with some reporting significant associations (Morris et al., 1996; Schwartz et al., 2000, 1997; Morris et al., 1998; Aramini et al., 2000; Gilbert et al., 2006; Beaudeau et al., 2012, 2013), whereas others did not (Tinker et al., 2010; Lim et al., 2003). Mann et al. (2007), reviewed the turbidity and AGII TSS and concluded on the likeliness of the association between turbidity and GI illness in some settings. These differences in conclusions may reflect true differences in risk between locations with different source waters and treatment regimens.

In TSS, daily counts of hospital admissions for AGII are fit to a Poisson distribution whose mean is allowed to vary as a smooth function of time (to capture trends in population level, vulnerability, and seasonal patterns mainly due to winter viral infections (Lopman et al., 2011)) and to vary as a function of weather and exposure variables that serve as surrogates for potential exposure to waterborne pathogens. Results have varied likely reflecting differences in drinking water systems and the extent to which the surrogate exposures reflect variations in true exposure. The most common surrogate has been turbidity, and to date only one study has examined a suite of potential surrogates (Beaudeau et al., 2013).

Here, we used a Poisson regression to first determine whether there was an association between AGII admissions and both turbidity and the change in disinfection method, and then to assess changes in risk associated with turbidity (raw and adjusted for algae), fecal coliforms (FC), UV-absorbance, algae and cyanobacteriae concentrations. Daily weather and rainfall data were also considered. We finally examined delayed risks and the sensitivity of the risk estimates to variations in model and data.

2. Data and methods

2.1. Water system

The Massachusetts Water Resources Authority (MWRA) supplies wholesale water to local water departments in 48 communities: 42 in greater Boston and the MetroWest areas, and three in Central Massachusetts.

The Wachusett and Quabbin Reservoirs, located about 35 and 65 miles west of Boston respectively, provide raw water for the MWRA. The reservoirs are filled naturally, and land use and access restrictions protect both reservoirs.

The Carroll Water Treatment Plant (CWTP) treats the water for the greater Boston and MetroWest areas. Treatment included chlorination and chloramination up to August 2005, and ozonation and chloramination afterward. Within both the chlorine and ozone periods, the injection rates were raised to adapt to regulatory changes. The chlorine CT (concentration × time) set in August 1998 was intended for *Giardia* inactivation, whereas the shift from chlorine to ozone in August 2005 sought to reduce *Cryptosporidium* risk. At the end of the study period, the relevant treatment sequence consisted of ozonation (for primary disinfection), fluoridation, chlorination, injection of ammonia to form chloramines for secondary disinfection, and of sodium carbonate and CO_2 for pH adjustment.

Evaluating the residence time of the water in the distribution system is crucial for relating potential exposure to potential health outcome. It takes about 5 h for water to move from the Wachusett reservoir to CWTP; then another 2–3 days from CWTP to the client towns.

In the Boston area, as with many urban areas, the distribution networks are gridirons, i.e., that the water can reach any service line by at least two different paths, ensuring permanent feeding and avoiding dead-ends. This kind of network results in complex waterways and variable residence-time distribution. Hence, the transit to taps may take several days and longer under extreme conditions.

Lastly, as the demand varies from 680,000 m^3 per day in winter to 900,000 m^3 per day in summer, the residence time of water in the water system increases by one quarter from summer to winter.

Operators (Sung, 2009) estimated that the mean time of water detention from chlorine injection point (Wachusett reservoir outlet, then CWTP) to consumers' taps was 3–5 days and that the maximum reached more than 10 days in Marblehead during the winter.

2.2. Study area

The MWRA services 2.5 million people overall. Cities partially fed by MWRA's water or receiving water processed elsewhere than at the CWTP were excluded from the analysis. The population of the study area (24 municipalities in Metrowest and Boston) was 1.504 million people in 2000. Of this population, those aged 65 years and older represented 201,000 people in 2000 (13.3% of the total population, half of them $\geq$75).

2.3. Morbidity data

Medicare is a national insurance program covering hospital admissions for persons aged 65 and older. All hospitals treating Medicare patients must submit standardized reports to the Health Care Financing Administration (HCFA) for each admission. From these reports we selected emergency admissions (excluding visits, transfer from another hospital or scheduled admissions) and extracted the date of admission, zip code of residence, and the International Classification of Diseases, 9th revision (ICD-9) code for the discharge diagnosis for all residents with a zip code of residence in the study area. We restricted our study to ICD-9 codes plausibly related to AGII, including a primary diagnosis of AGII (ICD-9 codes 001 to 009.9 and 558.9) or associated general symptoms such as electrolyte disorders (ICD-9 276), nausea and vomiting (ICD-9 787), and abdominal pain (ICD-9 789). Symptom codes and the general "catch-all" 558.9 categories were included because there is evidence of coding biases, especially attributing a non-infectious origin to AGII among the elderly (Gangarosa et al., 1992). From these data we tabulated daily counts of hospital admissions for AGII for each day from January 1, 1998 to December 31, 2008, for persons aged $\geq$65. The zip code changes that occurred in 1998 were included.