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Efficacy of water treatment processes and endemic gastrointestinal illness – A multi-city study in Sweden

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ABSTRACT

Outbreaks of acute gastrointestinal illnesses (AGI) have been linked to insufficient drinking water treatment on numerous occasions in the industrialized world, but it is largely unknown to what extent public drinking water influences the endemic level of AGI. This paper aimed to examine endemic AGI and the relationship with pathogen elimination efficacy in public drinking water treatment processes. For this reason, time series data of all telephone calls to the Swedish National Healthcare Guide between November 2007 and February 2014 from twenty Swedish cities were obtained. Calls concerning vomiting, diarrhea or abdominal pain (AGI calls) were separated from other concerns (non-AGI calls). Information on which type of microbial barriers each drinking water treatment plant in these cities have been used were obtained, together with the barriers' theoretical pathogen log reduction efficacy. The total log reduction in the drinking water plants varied between 0.0 and 6.1 units for viruses, 0.0–14.6 units for bacteria and 0.0–7.3 units regarding protozoans. To achieve one general efficacy parameter for each plant, a weighted mean value of the log reductions (WLR) was calculated, with the weights based on how commonly these pathogen groups cause AGI. The WLR in the plants varied between 0.0 and 6.4 units. The effect of different pathogen elimination efficacy on levels of AGI calls relative non-AGI calls was evaluated in regression models, controlling for long term trends, population size, age distribution, and climatological area. Populations receiving drinking water produced with higher total log reduction was associated with a lower relative number of AGI calls. In overall, AGI calls decreased by 4% (OR = 0.96, CI: 0.96–0.97) for each unit increase in the WLR. The findings apply to both groundwater and surface water study sites, but are particularly evident among surface water sites during seasons when viruses are the main cause of AGI. This study proposes that the endemic level of gastroenteritis can indeed be reduced with more advanced treatment processes at many municipal drinking water treatment plants.

1. Introduction

Insufficient drinking water treatment has led to outbreaks of acute gastrointestinal illnesses (AGI) on numerous occasions worldwide (Karanis et al., 2007; Hrudey, 2004; Guzman-Herrador et al., 2015). Recognized drinking water-related outbreaks of AGI might, however, just be the tip of the iceberg. To what extent pathogens in public drinking water contribute to sporadic cases within the endemic level of AGI is largely unknown (Reynolds et al., 2008).

Sporadic transmission of pathogens through drinking water could be a result of short-term malfunctions within the water treatment system or that the water treatment technique is unable to effectively eliminate pathogens that might be present in the incoming raw water. The pathogen-elimination barriers used in drinking water treatment plants either remove or kill microorganisms. Examples of barriers that remove pathogens are chemical coagulation and flocculation and different types of membrane filtration, while disinfection such as ozone, chlorination, and ultraviolet (UV) light is used to kill pathogens. Different types of barriers have different efficacies in reducing pathogens in general, and in some cases they can be more or less efficient in reducing specific pathogen groups (Smeets et al., 2006). For example, chlorination might eliminate bacteria and many of the viruses, but it is

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not effective in eliminating protozoans (Barbeau et al., 2000). Drinking water plants therefore often use multiple barriers, and the number of barriers often depends on the expected quality of the incoming raw water. Groundwater sources are generally considered to be less inclined to microbial contamination than surface waters, and thus groundwater plants often use a less advanced treatment technique (Smeets et al., 2006).

The barriers' efficacy in terms of relevance to public health is difficult to assess. Because AGI is usually self-treated and can be of relatively short duration, only a small fraction of the cases seek medical attention, and the cause of infection for sporadic cases (cases not linked to outbreak situations) is rarely determined. There are, however, studies that have used data of daily hospital admissions within periods of normal endemic variation, and these have linked increased numbers of AGI cases with, for example, elevated drinking water turbidity (Mann et al., 2007; Aramini et al., 2000; Beaudeau et al., 2014; Morris et al., 1996). Cohort studies that have used self-reported AGI have also linked increased AGI with different drinking water quality parameters (Egorov et al., 2003; Borchardt et al., 2012).

In Sweden, the *nurse advice line* (Swedish National Healthcare Guide 1177) is a relatively new database that can be used for studying population morbidity. The nurse advice line is a telephone service (phone number: 1177), available 24 h a day, and is intended for triage of non-emergency concerns and is offered to the majority of the population. Nurses record the topic of all phone calls in predefined classifications, and they give advice for treatment or recommend visits to clinics for medical examination. This database has previously been used studying AGI and linked preceding heavy rainfall to temporal increased number of calls issuing AGI (Tornevi et al., 2013). It has also been shown to be the most useful data source for early warning with regard to AGI outbreaks (Andersson et al., 2014). Furthermore, even though it can be assumed that only a fraction of actual cases calls a nurse for advice during AGI, it has been shown that the nurse advice line captures many more cases than visits to primary health clinics regarding AGI-related symptoms do, especially during seasons when viral agents are the most common causes of AGI (Tornevi et al., 2015).

The present study used data from the nurse advice line with the aim to compare the endemic levels and seasonal patterns of AGI between populations receiving municipal drinking water from surface water or groundwater sources with different treatment methods. The methodology can be used to evaluate microbial barriers used in drinking water production and their relevance to public health. The study is also relevant in light of climatic change, where many areas worldwide are facing new threats regarding drinking-water safety (Delpla et al., 2009). For example, more frequent events of heavy rainfall may result in increased risk of pathogens entering raw water supplies, and data for preventive measures are therefore needed.

2. Materials and methods

2.1. Data and definitions

2.1.1. Study areas

Twenty Swedish municipalities with a locality (town/city) exceeding 20,000 inhabitants were selected for the study. The municipalities were selected from all parts of the southern half of Sweden, and the municipal drinking water production in the main locality was represented by one or two large water treatment plants, receiving water from ground or surface water sources. None of the selected municipalities reported any drinking water-related AGI outbreaks during the study period. Postcode data for each locality was achieved (according to the 2010 definition of localities, Statistics Sweden, 2010) to determine the postcodes with addresses receiving drinking water from the municipal drinking water plants (i.e. to exclude addresses from rural parts of the municipality that may receive drinking water from other sources, for example private wells).

2.1.2. Outcome

For the selected postcode areas, data on all telephone calls to the nurse advice line (which is commonly referred to by its phone number, 1177) between 2007-11-28 and 2014-02-28 were obtained. For all calls, the date, the postcode, and recorded subject of the call were obtained. Calls where the main symptom was recorded either as vomiting and nausea, diarrhea, or abdominal pain were defined as cases of AGI (AGI calls). The AGI calls were also classified into those regarding children (below 16 years of age) and those regarding adults (16 years or older). Calls concerning 'H1N1 influenza' were removed from the data because this classification was only used temporarily during the pandemic in 2009. Other recorded subjects of the calls were defined as non-gastrointestinal symptoms (non-AGI calls). For a few municipalities, data were not available for the first period of the study (the latest start of data collection was May 2009).

2.1.3. Exposure

For each city, the barriers in the main water treatment plant were identified together with the water source used for production (surface or groundwater). For the largest city in the study, there were two similarly sized water treatment plants and the distribution areas for the two plants were treated separately in the analyses resulting in 21 study sites.

For each of the water treatment plants, the theoretical efficacy of pathogen elimination by the barriers was calculated using data from the research project *Microrisk* (Smeets et al., 2006) and from the study of Westrell et al (Westrell, 2004). (see supplemental Table S1). Because different barriers (filtration, chlorine, UV light, ozone) were defined with different capacities to eliminate different pathogen groups (viruses, bacteria, protozoa), three separate efficacy quantities (log reductions) were derived for each water treatment plant. One unit log reduction corresponds to a ten-fold (90%) reduction of microorganisms. To derive one general efficacy parameter for each water treatment plant, a weighted log reduction (WLR) was calculated (a weighted mean value) according to the contribution of each pathogen group to AGI in the general population. De Wit et al (De Wit et al., 2001). investigated the occurrences of different infectious agents among community cases of AGI, and they found that 78.9% of the cases were infected by viral pathogens, 5.3% were of bacterial cause, and protozoans was determined as the cause of AGI in 15.8% of the cases. These proportions were used as weights when calculating the WLR for each water treatment plant. Consequently, a barrier with a higher capacity for eliminating pathogens that more commonly give rise to infections in the population (e.g. viruses) is also given a higher weight, and thereby increasing the WLR.

One drinking water plant had upgraded their treatment process in 2010 (UV light was installed), and this was accounted for when calculating the WLR. Three drinking water treatment plants upgraded their process by installing UV lights during the second half of 2013, but this short remaining part of the study period was not accounted for when calculating the WLR.

Besides considering the WLR as a continuous exposure variable and hypothesizing a linear relation to the outcome, we categorized WLR uniformly into 'low', 'medium', and 'high' to account for possible non-linear associations. Moreover, because our study sites included drinking water plants using groundwater or surface water, for which microbial levels cannot be assumed to be similar, we