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Waterborne Diseases: Linking Public Health and Watershed Data

Debalina Das
University of Massachusetts - Amherst

Sarah M. Dorner
University of Massachusetts - Amherst

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Waterborne Diseases: Linking public health and watershed data

Debalina Das[1], Sarah M. Dorner[2,3]
[1]Department of Public Health, [2]Massachusetts Water Resources Research Center,
[3]Department of Civil and Environmental Engineering, University of Massachusetts Amherst

Abstract

Microbial contaminants in water are a major public health concern. Pathogens have been identified as a primary threat to river water quality in the United States, potentially impacting drinking and irrigation water sources and recreational waters. Agricultural runoff, feedlot operations, wastewater effluents, swimming activities, domestic and wild animals are potential sources of microbial contamination. Quantitative microbial risk assessment provides a useful framework for estimating the risk of illness as a result of exposure to pathogens; however, very little information is available with regards to the impact of watershed conditions on the prevalence of illnesses. A challenge for microbial risk modeling pertains to quantitatively estimating sources of pathogens in the environment and their fate and transport in various media. Prior to the development of a microbial risk model, primary pathogen sources, pathogens of concern, the receptors, and the routes of exposure need to be established. This paper presents Massachusetts as a case study for linking public health data of waterborne diseases with sources of drinking water, potential recreational exposures, as well as hydrologic, climatic, and land use data. Information of reported illnesses from known waterborne pathogens will be synthesized and the relationship of confirmed illnesses will be compared with available hydrologic data. The goal is to develop a pathogen vulnerability index for Massachusetts waters to improve estimates of exposure to pathogens given watershed conditions.

Introduction

Microbial contamination of water is a major problem for human health and has led to large waterborne disease outbreaks (e.g. Mackenzie et al., 1994; O'Connor, 2002). Drinking and recreational waters can be highly susceptible to microbial contaminants with pathogens frequently observed in surface and groundwaters (Lemarchand and Lebaron, 2003; Hancock et al., 1998).

Zoonotic pathogens (pathogens transmissible between animals and humans) are of increasing concern. Almost three fourths of the emerging infectious diseases are animal borne or zoonotic. In recent decades, infectious pathogens originating from wild animals are become increasingly important throughout the world. The concern is not only for the impacts on human health but also for the long term impacts on agricultural production, wildlife-based economies and wildlife conservation (Chomel et al., 2007). In the United States, *Giardia*, *Campylobacter*, *Cryptosporidium*, *Salmonella*, and *E. coli* have been the most commonly identified zoonotic agents of waterborne disease outbreaks (Craun *et al*. 2004).

Exposure to Pathogenic Microorganisms

From 1999 to 2000, 59 diseases out breaks in the US were reported related to recreational water exposure and 61% of this involved gastroenteritis (Alm et al., 2003). Recreational water includes water in swimming pools, hot tubs, jacuzzis, fountains, lakes, rivers, springs, ponds, or streams that can be contaminated with sewage or feces from humans or animals. In 1986, the United

States Environment Protection Agency (US EPA, 1986) examined the association between densities of *Escherichia coli* and Enterococci present in recreational water and gastrointestinal illness in swimmers and then based their bathing water quality standards on these indicator bacteria. Enterococci and *Escherichia coli* are commonly present in beach water and fresh recreational water (Haack et al., 2003).

The standard for microbial contaminants in drinking water is zero (EPA, 2006). Drinking water sources become contaminated when feces containing pathogens are deposited or flushed into water. If treatment is insufficient, drinking water may contain sufficient numbers of pathogens to cause illness (e.g. O'Connor, 2002).

Large multi-state outbreaks, such as the *E. coli* O157:H7 outbreak from fresh bagged spinach in September 2006 have occurred (CDC, 2006). In the United States and other Central American countries, 60% of the total irrigation water (mainly for vegetables) has been found positive for *Giardia* cysts following testing. *Giardia* cysts have been found on wastewater irrigated coriander, carrots, mint, radishes and potatoes. Contaminated fruits and vegetables related to outbreaks have been reported frequently (Fayer, 2004). *Giardia* has also been detected in shellfish. In *Macoma* clams in the Rhode River, *Giardia duodenalis* genotype A was identified, also suggesting that these clams can be used as bio-indicators of water contamination (Fayer, 2004).

Human to human transmission can occur following the accidental ingestion of cysts in contaminated water or food, or from direct contact with environments with compromised hygiene levels. Direct person to person transmission may be more common in some types of communities or institutional settings such as day care centers. Infectious diarrhea has been recognized as one of the most important health problems for young children at day care centers with the incidence of diarrhea being twice as high for children in day care as compared to children cared for at home (Thompson, 2000).

Travel to regions of the world with inadequate access to clean water has long been associated with an increased risk of diarrheal illness. For example, it has been reported that even among travelers to Eastern European countries and in the former Soviet Union, the increased risk of waterborne giardiasis is well recognized. (Dawson, 2005).

Environmental Factors Leading to Exposure

Understanding the contributions of land use and watershed protection measures is important for assessing microbial risks. In Ontario, *E. coli* O157:H7 cases were found to be more common in rural areas where direct and indirect contact with livestock sources of pathogens may be more common (Michel et al, 1999). Agricultural activities such as intensive livestock farming (such as concentrated animal feeding operations) do not exist in Massachusetts. However, urban land use may be associated with the presence of aging infrastructure that may contribute to pathogen contamination events. Approximately 772 cities in the U.S. have combined sewer overflow systems (CSOs) (EPA, 2007). In Massachusetts, the city of Lowell has a CSO on the Merrimack River for which in 2006 the Clean Water State Revolving Fund had granted $14,000,000 for rehabilitations (Commonwealth of Massachusetts, 2006). It is important to consider the effects of combined sewer overflow systems on numbers of gastrointestinal illnesses.

Climate has been linked to infectious diseases, and the use of climate information has been recommended for early warning systems for epidemics (e.g. WHO, 2005). There is growing evidence that weather is often a factor in waterborne disease outbreaks (Hrudey et al., 2002). With expected increases in precipitation in the Northeastern United States from climate change (Hayhoe et al., 2007) there is the possibility that there will be alterations in risk of waterborne illnesses associated with heavy precipitation. Increases in precipitation could intensify flooding, and increase the potential for surface and groundwater contamination by enteric pathogens. Furthermore, flooding could decrease the effectiveness of water treatment.

Curriero et al. (2001) found a statistically significant association between rainfall and disease in the United States – 51% of waterborne disease outbreaks were preceded by precipitation events above the 90^{th} percentile (P=0.02). In addition, 68% of waterborne disease outbreaks were preceded by precipitation above the 80^{th} percentile (P=0.01). Newer analyses continue to support conclusions that an increase in the frequency and severity of extreme precipitation events from climate change will result in an increased risk of waterborne and food borne illnesses with the most vulnerable groups being the very young (< 1 year of age), older adults (> 65 years of age) and immunocompromised individuals (Ebi et al., 2006).

Goals and Objectives

An overall goal of the study was to determine the extent of potential waterborne exposures to pathogenic microorganisms. This is being accomplished through the analysis of the spatial and temporal variability of confirmed reported human cases of *Giardia* in Massachusetts. *Giardia* was selected as a reference pathogen for several reasons: (1) it is one of the most commonly identified etiologic agents in waterborne disease outbreaks; (2) it has a multitude of environmental sources that may be influenced by watershed hydrology; (3) it is more resistant to conventional treatment (Hoff, 1986) than the bacterial pathogens and thus confirmed human cases are more likely to occur from a waterborne route (as compared to other pathogens that are more easily removed from treatment processes).

Giardia is a waterborne zoonotic protozoan parasite that is found all over the world and is one of the most frequently reported parasites of humans and animals. *Giardia* cysts are transmitted by the fecal-oral route of humans and animals and have an incubation period of 7 to 14 days (Fayer et al., 2004). A common source of *Giardia* is sewage effluent and it has been found in the feces of domestic animals, livestock and wild animals. The cysts in animal and environmental samples have been shown to be infective to humans (Thompson, 2000). Of genetic groupings of *Giardia duodenalis*, there have been two assemblages, A and B that are known to be zoonotic. Assemblage A has been shown to infect humans, livestock, dogs, cats, beavers, guinea pigs, slow loris, mountain gorillas, rock hyrax, harp seals, hooded seals, deer, prairie dogs, bobcats, groundhogs and domestic mice. Assemblage B infects humans, cattle, dogs, cats, beavers, musk rats, slow loris, siamang, chinchillas, rats, coyotes and domestic mice (Appelbee, 2005).

The relationships between precipitation, streamflow, broad watershed characteristics and confirmed human cases of *Giardia* were examined. The hypotheses for this research consider two time scales: (1) seasonal time scales that may provide an indication of changes in patterns of

human contact with pathogens over the course of a year, and (2) daily time scales that are related to rapidly varying environmental conditions such as precipitation, temperature, increased stream flow and runoff etc. In addition, the spatial variability of gastrointestinal illnesses is expected to be significant, as some watersheds are expected to have fewer sources of pathogens in the environment.

The hypotheses were the following:

(1) Seasonal time scale: Human recreational behaviors, seasonal uses of water, and seasonal access to water all play an important role in disease outbreak. Cases of reported human *Giardia* infections in Massachusetts will demonstrate a seasonal trend with peaks occurring during expected periods of greatest exposure to pathogens.
(2) Daily time scale: Periods of intense precipitation and higher stream flow will lead to an increase in the number of cases of human *Giardia* infections in the Merrimack River Watershed.
(3) Watersheds with a larger amount of urban land cover will have more cases (per 100,000) of human *Giardia* infections than watersheds that are predominantly forested and rural. The Merrimack River Watershed with combined sewer overflows in its drinking water sources will have more human cases per 100,000 of *Giardia* infections than other watersheds of Massachusetts which don't have CSOs in their drinking water sources.

The specific objectives of the research were to:

1. Determine and explain any seasonal trends in confirmed human cases of *Giardia* infections, and whether a waterborne route of transmission is consistent with any observed seasonal trend.
2. Determine the potential impact of precipitation and increased stream flow on numbers of confirmed human cases of *Giardia* infections.
3. On watershed basis, depending on land use (urban versus rural) or the presence of Combined Sewer Overflows (CSOs) upstream of a drinking water intake, determine if there is a significant difference in the frequency of reported confirmed *Giardia* cases.

Materials and Methods

Study Areas

Three watersheds in Massachusetts are being studied in detail. They are: (1) the Blackstone River Watershed, (2) the Deerfield River Watershed, and (3) the Merrimack River Watershed.

Blackstone River Watershed – This watershed is a series of streams originating in the hills of Worcester, Massachusetts. The Blackstone River flows 48 miles in Massachusetts south into Rhode Island. It has a total drainage area of 640 square miles; about 382 square miles are in Massachusetts. The Blackstone River Watershed also encompasses 1300 acres of lakes, ponds, and reservoirs. Worcester and Providence, the second and third largest population centers in New England, are in the Blackstone River Watershed. In the early 19th Century, immigrants to the region took advantage of the natural water power of the Blackstone River, which became the "Birthplace of America's Industrial Revolution" (EOEA, 2007). The Blackstone River Watershed

was selected as being representative of an urban, highly contaminated watershed. Based upon U.S. Census data for the year 2000, the calculated total Massachusetts population of the Blackstone River Watershed is 340,297.

Deerfield River Watershed – The Deerfield River is one of the coldest and cleanest rivers in Massachusetts. It drops approximately 2000 feet from its headwaters to its convergence with the Connecticut River. Its drainage area is approximately 665 square miles; most of its headwaters are located in the Green Mountains of southern Vermont. The Deerfield River Watershed includes more than 149 streams, 21 lakes and ponds (EOEA, 2007). Based upon U.S. census data for 2000, the Massachusetts population in the Deerfield River Watershed is 31,337. It is renowned for its whitewater and high water quality, which have encouraged multiple recreational uses of the river such as sport fishing, kayaking and canoeing. The Deerfield River Watershed was selected as being representative of a rural watershed with low contamination.

Merrimack River Watershed – The Merrimack River Watershed is the fourth largest watershed in New England. The river flows south through central New Hampshire for 78 miles and into Massachusetts. The total drainage area of Merrimack River Watershed is 5,010 square miles among which 1,200 square miles are in Massachusetts. It includes all or part of 24 Massachusetts municipalities (EOEA, 2007). Lowell is one of the major towns of this watershed. Several communities along the Merrimack River obtain their drinking water from the river. The drinking water sources are potentially impacted by combined sewer overflows (CSOs). In a CSO, storm water is mixed with untreated wastewater and discharged to the river prior to complete treatment. In Lowell, nine CSOs can discharge more than 10 million gallons of sewage and storm water during a one-inch rainstorm (EPA, 2007). The Merrimack River was selected as it is representative of a watershed with important sources of drinking water contamination.

Precipitation, Land Use, and Streamflow Data

ArcGIS 9.2 (ESRI, Boston, MA) software was used for GIS analysis for processing land use, census population, and watershed delineation data files. The base maps were acquired from MassGIS (MassGIS, 2006). Hydrologic data were downloaded from the U.S. Geological Survey (USGS, 2006) database for a gauge in each of the study watersheds. Daily precipitation and temperature were downloaded from the NOAA database for a gauge in each of the study watersheds (NOAA, 2006).

Public Health Data

Datasets of confirmed human cases of giardiasis, shigellosis, cryptosporidiosis, campylobacteriosis, and shiga toxin-producing *E. coli* were obtained from the Massachusetts Department of Public Health with city and zip code for the years 1988 to 2006. In addition, reports of all identified waterborne disease outbreaks for the same period were obtained. Of the thousands of confirmed cases of illness, very few are associated with documented waterborne disease outbreaks. Most of documented waterborne disease outbreaks in Massachusetts were from recreational waters that included both fresh lake/pond water or swimming pool/hot tub waters. Confirmed etiologic agents from the outbreaks included *Legionella pneumophila, Giardia, Cryptosporidium,* and *Shigella sonnei.*

Statistical Analysis

Statistical analysis was performed using SPSS 14.0 (SPSS Inc., Chicago, Illinois).

Results and Discussion

T-tests were performed to evaluate the effects of land use and CSOs on human cases of giardiasis. It was found that there was no significant difference (P = 0.546) between the urban watershed (Blackstone River Watershed) and the rural watershed (Deerfield River Watershed) with regards to confirmed cases of giardiasis. However, the watershed with drinking water supplies impacted by combined sewers (Merrimack River Watershed) had significantly higher numbers of confirmed cases of *Giardia* infection (P=0.003) as compared to the urban watershed (Blackstone River Watershed). Figure 1 presents the total annual number of cases per 100,000 people for the three watersheds.

The Merrimack River Watershed has the highest incidence of giardiasis, and thus long term average precipitation and streamflow data are presented in Figures 2 and 3 for gauges at Lowell, a city within the watershed. Streamflow is greatest in the spring when snowmelt occurs, declines during the summer, and then increases in the fall when precipitation increases. October is the month with the highest average total monthly precipitation. Long term (1988-2006) averages of total monthly confirmed cases show that the month of August has the highest numbers of reported cases of *Giardia* (Figure 5). The peak of *Giardia* cases in the summer is consistent with the hypothesis that recreational waters are a primary route of transmission for the parasite. It is also interesting to note that among months for which no outdoor waterborne recreational exposure will likely occur, October has the highest number of confirmed cases, and February, the lowest. As can be seen in Figure 4, October has the greatest amount of precipitation, and February, the least. Streamflow at a monthly time scale is not related to incidences of confirmed *Giardia* cases. The reason for a lack of relationship between streamflow and illness appears to be that exposures to pathogens in the environment are greatest during the summer months when streamflow is lowest. Furthermore, illnesses are low in the spring, when streamflow is highest. However, it is possible that some of these infections were acquired by other routes of transmission such as food or person to person contact.

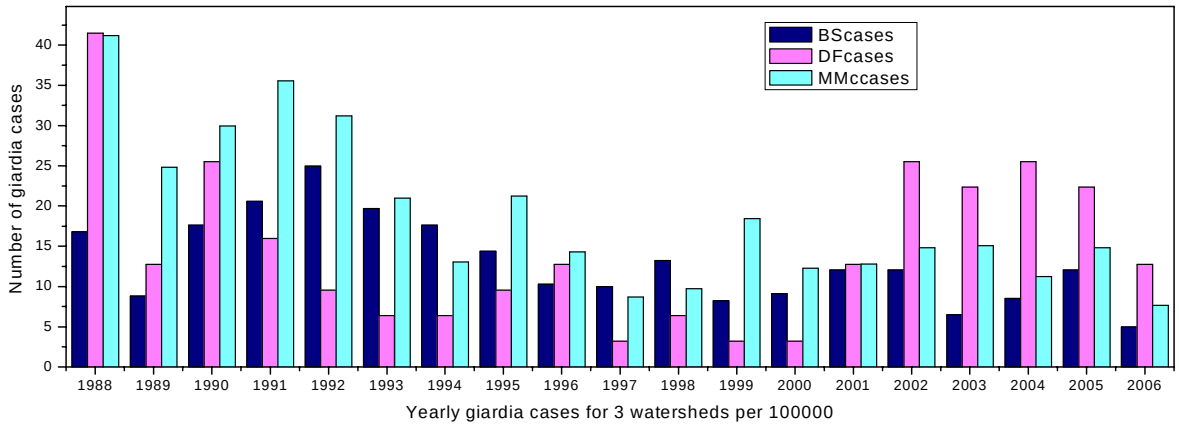

Figure 1. Total annual confirmed *Giardia* cases in the Blackstone (BS), Deerfield (DF), and Merrimack (MMc) River Watersheds.

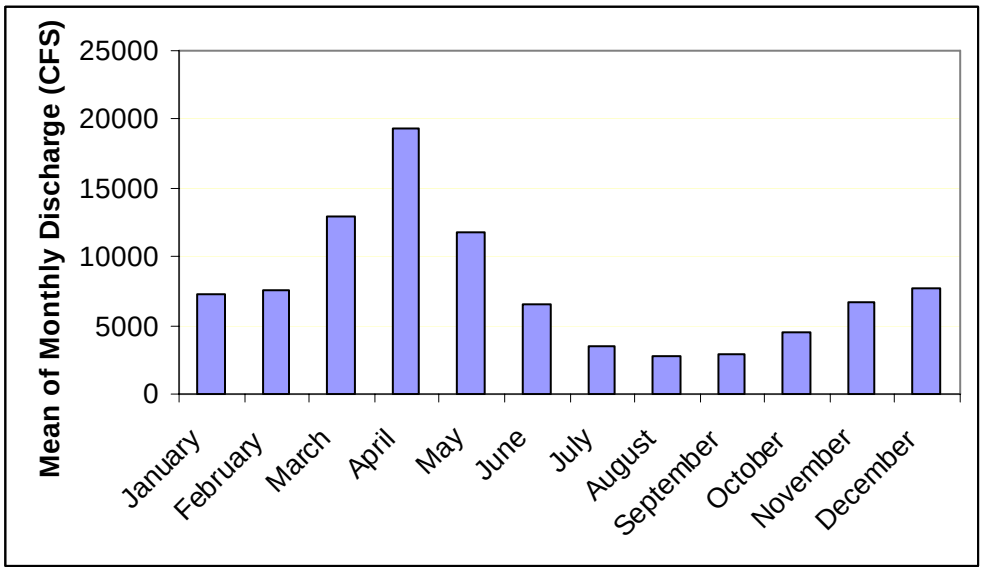

Figure 2. Mean of Monthly Discharge of the Merrimack River at Lowell, Massachusetts (USGS 01100000, 1924-2006).

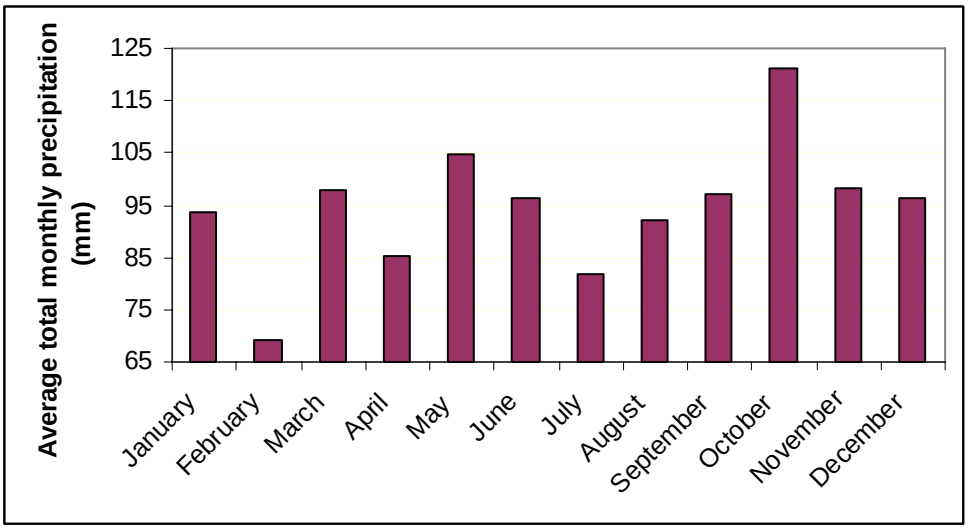

Figure 4. Average total monthly precipitation in Lowell, Massachusetts (NOAA 194313, 1988-2006).

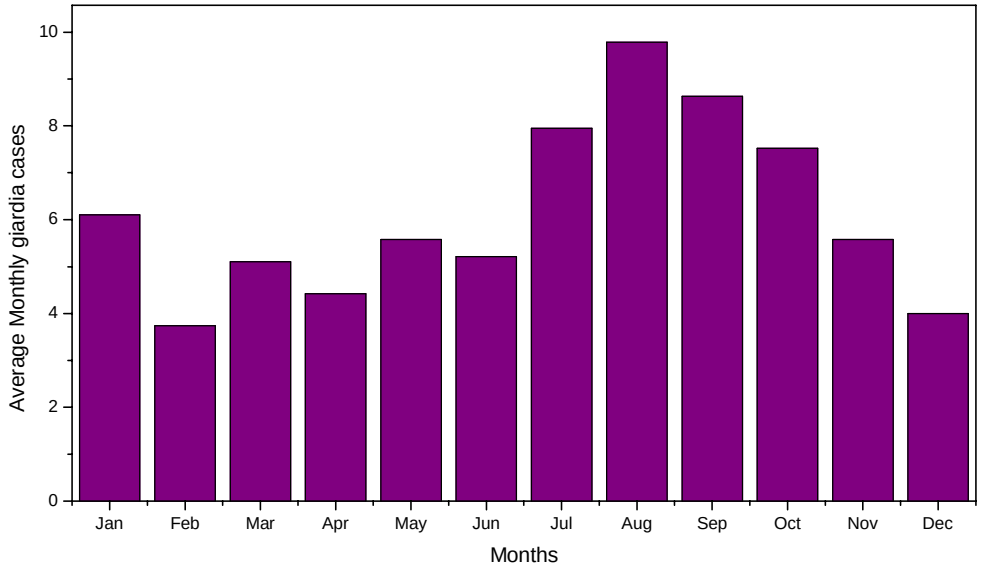

Figure 5. Average confirmed monthly cases of *Giardia* in the Merrimack River Watershed (1988-2006).

Seasonal trends are one of the major characteristics of gastrointestinal illnesses (WHO, 2005). There is evidence of seasonal trends in microbial pathogen occurrence in the environment (e.g. Ong *et al.*, 1996), the public health significance of which is unknown. However, because of the costs associated with pathogen monitoring, data are often not collected for long enough periods to properly determine the seasonality of pathogen occurrence.

As human behavior (winter-summer differences) and recreational patterns change over the seasons, seasonal differences of human behavior may be contributing to exposures to waterborne pathogens. This research is expected to enlighten the seasonal trends of reported gastrointestinal diseases depending on seasonal use of water, in selected watersheds in Massachusetts. Furthermore, results show that the human population in watersheds with drinking water supplies impacted by combined sewer overflows is at a greater risk for exposure to *Giardia*.

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Author contact information:

Sarah M. Dorner, Director
Massachusetts Water Resources Research Center
Blaisdell House, 310 Hicks Way
University of Massachusetts Amherst
Amherst, MA 01003
(413) 545-5528
sdorner@tei.umass.edu