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Use of quantitative microbial risk assessment to improve interpretation of a recreational water epidemiological study☆

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ABSTRACT

We conducted a supplemental water quality monitoring study and quantitative microbial risk assessment (QMRA) to complement the United States environmental protection agency's (U.S. EPA) National Epidemiological and Environmental Assessment of Recreational water study at Boquerón beach in Puerto Rico to estimate the gastrointestinal (GI) illness levels associated with recreational water exposures. The previously reported epidemiological study had sufficient statistical power to detect an average illness rate of approximately 17 swimming associated GI illnesses per 1000 recreation events or greater, and found no consistent relationships between water quality measured by fecal indicator organisms (FIO) and swimming-associated illnesses (U.S. EPA, 2010a). The QMRA incorporated monitoring data for pathogens and fecal indicators collected during the epidemiological study period and calculated average swimming-associated illness levels that were approximately two GI illnesses per 1000 recreation events. To our knowledge, this is the first time that a comprehensive water quality monitoring program and QMRA analysis has been conducted in parallel with a recreational water epidemiological study. The QMRA results were consistent with the low rate of reported illnesses during the 2009 epidemiological study (i.e. <17 GI illnesses per 1000 recreation events) and provide additional context for understanding the epidemiological results. The results illustrate that coupling QMRA with an epidemiological study at a single study site provides a unique ability to understand human health illnesses especially under conditions where water quality, as measured by traditional FIO is good and/or average illness rates are lower than can be quantified via epidemiological methods alone.

1. Introduction

The United States Environmental Protection Agency (U.S. EPA) conducted a recreational water epidemiological study at Boquerón beach during the summer of 2009. This study was one of a series of epidemiological investigations conducted at nine fresh water, marine, tropical and temperate beach locations in 2003, 2004, 2005, 2007, and 2009 by the U.S. EPA as part of the National Epidemiological and Environmental Assessment of recreational water (NEEAR) study (U.S. EPA, 2010a; Wade et al., 2008, 2010). The Boquerón beach study examined swimmers' health after swimming in tropical marine waters and measured water quality with new and faster ways of testing for microbial indicators (U.S. EPA, 2010a). Health surveys and interviews commenced at Boquerón beach on May 16, 2009 and concluded on August 2, 2009 with a total of 15,726 individuals enrolled in the study. Swimmers were defined as those who, at a minimum immersed their body in the water. Illness symptoms studied included: gastrointestinal (GI) illness, respiratory illness, skin rash, earache, and eye irritations. GI illness was as defined in Wade et al. (2006) and Colford et al. (2007). EPA refers to this type of GI illness as NGI (U.S. EPA, 2010a, 2012). Notably, NGI does not require the presence of a fever, which differentiates it from previous definitions of GI illness

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(commonly referred to as HCGI – Highly Credible Gastrointestinal Illness) (U.S. EPA, 1986). Swimmers reported higher rates of illnesses than non-swimmers, but illness rates were not associated with fecal indicator organism (FIO) levels (U.S. EPA, 2010a). These results indicate that swimming-associated illness levels were not associated with FIO at the beach study site and were below the level that the epidemiological study was designed to detect.

Concurrently, we conducted a water quality monitoring study at Boquerón beach to gather the additional data necessary for the conduct of a quantitative microbial risk assessment (QMRA). Previously, we illustrated the power of considering epidemiological results and QMRA estimates together (Soller, 2010a). Our initial intention for this study was to assess the calculated QMRA illness estimates against the empirical results of the epidemiological study. When the epidemiological study reported unexpected results, we were able to use the QMRA to help interpret those epidemiological findings.

The water quality monitoring study involved the enumeration of pathogens and FIOs at the beach and nearby locations, including at potential contamination sources impacting the beach. In addition to the water samples collected specifically for the epidemiological study, water samples were contemporaneously collected at the beach site for analysis of a set of important pathogens (discussed below). Water samples were also collected for three other sample sites and analyzed for FIOs and pathogens.

This study uses QMRA methodologies to characterize the potential for GI illness from exposure to the water at Boquerón beach. QMRA is a formal process, analogous to chemical risk assessment, of estimating human health risks due to exposures to infectious pathogens (Haas et al., 1999; NRC, 1983). QMRA can supplement epidemiological results by characterizing various exposure scenarios, interpreting potential etiological drivers for the observed epidemiological results, and accounting for differences in risks posed by various types of FIO sources (Boehm et al., 2009; Dorevitch et al., 2011; Soller et al., 2010a,2010b). In particular, QMRA may have utility in recreational locations which are impacted by low levels of contamination or are non-effluent dominated (Colford et al., 2007, 2012; U.S. EPA, 2010b). For example, Eisenberg et al. (2006) utilized QMRA in a drinking water intervention study that had drinking water-associated illness levels that were too low to quantify via epidemiological methods. Viau et al. (2011a) used QMRA modeling to characterize the potential risk of GI illness from swimming in tropical marine waters adjacent to 22 streams on Oahu, Hawaii. While the median risk estimate for these streams was 0.01%, much higher risks (up to 2%) were estimated for exposure to stream waters that contained adenovirus (AdV) and/or norovirus (NoV) (an indication of human fecal loading).

Herein, we report the results of the water quality monitoring study and QMRA analyses using those water quality monitoring results. Specifically, we use QMRA to 1) estimate potential probability of GI illness levels due to water ingestion at Boquerón beach during the epidemiological study, and 2) provide additional information to assist in the interpretation of the epidemiological results.

2. Materials and methods

2.1. Study location and sampling sites

Boquerón Bay is a large horseshoe shaped bay in southwestern Puerto Rico. Boquerón beach is situated at the eastern side of the Bay and is approximately one mile long. It is gently sloping and shallow with fine sand, and is subject to little wave action. Nearby, there is a mangrove lagoon (hereafter referred to as the lagoon) that flows into Boquerón Bay and is accessible by boat from the beach. There are a total of three wastewater treatment plants (WWTPs) operating near the study location, each with their respective outfall. These three WWTPs are potential sources of human fecal contamination to Boquerón beach.

One WWTP (the Boquerón PRASA WWTP, hereafter referred to as the WWTP) discharges into the bay approximately 1 mile from the beach site. The WWTP serves a population of 13,200. The 0.25 million gallons per day (Mgal/D) facility employs activated sludge secondary treatment and disinfection via chlorination/dechlorination. The WWTP is often overloaded during the high tourist season (April–August) and commonly discharges from 0.26 Mgal/D to 0.60 Mgal/D.

In addition, two other smaller treatment plants (hereafter referred to as Package Plant #1 and Package Plant #2) serve apartment buildings and other beach facilities, and discharge into the adjacent lagoon which connects to Boquerón Bay, also less than one mile away. These facilities are each authorized to discharge up to 0.02 Mgal/D of effluent that is treated via aerobic digestion, disinfection by chlorination, and dechlorination. During heavy rain and high tourism periods, flows from these facilities often exceed the permitted plant capacities.

Other sources of fecal contamination may also flow into the lagoon. There is surface water input to the lagoon from overland flow and a canal. These flows drain areas where there are human and animal waste inputs; settlements and pasturage, for example. These are, of course, augmented in rainfall events and larger inputs might tend to shorten transit times for lagoon waters (including WWTP flows in addition to overflows), and resuspend settled material in the lagoon, both from outfalls and from normal flows.

For the water quality monitoring study (described in more detail below), samples were collected at four sites: Site 1 the WWTP – grab samples collected from the effluent before it enters the outfall pipe; Site 2 Boquerón beach – composite samples were created using equal portions of water collected at waist-depth from three beach transects; Site 3 Package Plant – grab samples collected immediately upstream from effluent entering the outfall pipe at Package Plant #2; and Site 4 lagoon – grab samples collected at the center of the channel at the mouth of the lagoon flowing into Boquerón Bay (Fig. 1).

2.2. Water quality monitoring study

Water samples were collected from each of the four sites (Fig. 1) on each weekend day for the epidemiological study duration –June 6, 2009 to August 9, 2009 and represent water quality on the same days represented by the epidemiological information on swimmer health. Water samples were analyzed for FIOs common to EPA regulations and pertinent for recreational waters, and for reference pathogens for recreational waters (Soller et al., 2010a). Water samples were collected at the Boquerón beach site during the epidemiological study and were analyzed for *Enterococcus* spp. and *Bacteroidales* spp. using quantitative polymerase chain reaction (qPCR) and enterococci using culture methods (U.S. EPA, 2010a). Additional FIO samples were collected at the beach and analyzed for *Clostridium perfringens* and male specific coliphage. FIO results for the beach site reported herein were collected at 8:00 a.m. at waist depth. To supplement the FIO data collected at the beach site, additional water samples were contemporaneously collected for analysis of pathogens that included NoV, AdV, enterovirus (EV), *Cryptosporidium* spp., *Giardia* spp., *E. coli* O157:H7, non-O157 shigatoxin *E. coli* strains, *Campylobacter*, and *Salmonella* spp. For the other three sample sites, water samples were collected and analyzed for FIOs [*Clostridium perfringens, Enterococcus* spp., *Bacteroidales* spp., enterococci, male specific coliphage, and *E. coli*] and the same pathogens listed above. An overview of the analyses is provided in Tables 2 through 4, and a description of each of the analyses is provided in the Supplemental Materials.

For the water quality monitoring study, grab samples were collected in sterile 1-L, 2-L or 4-L Nalgene containers and split for multiple FIO analyses. For the pathogen analyses, ultrafilters (UFs) were