Comparison of surfing health risk in dry weather and post-storm conditions using quantitative microbial risk assessment (QMRA) for Southern California beaches

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Abstract

Urban stormwater runoff brings numerous pollutants to the coastal waters, including human fecal pathogens. Elevated fecal indicator bacteria (FIB) in recreational waters are often correlated with elevated health risk of gastrointestinal illness (GI). This study investigated surfers' health risk of GI during dry weather and post-storm conditions in the coastal waters of Southern California based on enterococcus (ENT) and fecal coliform (FC) concentrations in water. Surfers are of particular interest because they prefer the large waves following a storm event and stay in the water for a prolonged period of time. Surfer exposure to pathogens was estimated based on the joint probability of water ingestion and FIB concentration using Monte Carlo simulation. Applying QMRA on three dose-response models, we found significant different health risk on the same beach using ENT or FC. We also found, using ENT, some beaches have significantly elevated health risks for surfers after a storm event.

Introduction

Southern California is a hot spot for surfing. However, surfing in California coast waters were reported to correlate with the elevated gastrointestinal illness (GI) and other adverse health symptoms during the winter months with the higher level of precipitation(Dwight et al., 2004). This observation is likely due to multiple factors:

- Urban and stormwater runoff transport urban pollutants to the coastal ocean (1, 2), which result in significant increase of fecal indicator bacteria (FIB) loading following a rainfall event (2)
- Surfers prefer the large waves that usually accompany a storm event (4, 5) and stay in the coastal water for a prolonged period of time (3), therefore exposing them to pollutants for a longer period of time than swimmers
- Delayed or erroneous warning posting (6) may misinform surfers, exposing them to contaminated coastal waters
- GI is the most frequent adverse health outcome of waters contaminated with FIB (7, 8)

Large-scale epidemiology survey of surfers who were exposed to the urban runoff contaminated coastal water post-storm is cost prohibitive. QMRA using available bacteriological water quality data and dose-response relationship offers the effective alternative to epidemiology study to quantify the health risk associated with surfing at post-storm conditions. Comparative risk analysis at dry weather and post-storm conditions also provides insights to policy decision of coastal and human health management.

Figure 1. Map of selected bacteriological monitoring locations (red dots) & weather stations (white square)

Methodology

We evaluated the dose-response risk of GI for surfing using enterococcus (ENT) and fecal coliform (FC) since different FIB chosen may produce different risk outcome.

FIB data between January 2008 and May 2010 were obtained through Los Angeles County Department of Public Health, Orange County Health Care Agency, SCCOOS, and San Diego County Department of Environmental Health at each beach locations indicated in Figure 1 and Table 1. The beach locations were chosen based on their popularity to surfers and availability of water quality data. Precipitation data during the period was retrieved from NCDC.

The FIB data were extracted using the following criteria:

- Weather stations recording rainfall must be in the vicinity of the chosen bacteriological monitoring locations
- Bacteriological data on the day of the rainfall event are not used as they may not reflect storm-impacted coastal water quality due to delays in storm water transport; storm-impacted data were restricted to 24 to 72 hours after a rainfall event
- Dry condition is defined in this study to have 0 inch precipitation recorded

Kernel distribution was chosen to fit (best fit) the base-10 logarithm of ENT and FC data (concentration C) for both dry and post-storm conditions. Monte Carlo simulation was performed using a MATLAB® program and by randomly sampling under the fit curve for 10000 iterations. Surfer seawater ingestion volume (I) (9), swimmer water ingestion rate (R), and exposure time (T) (10) were collected through literature review. Their range of values also were also randomly sampled to estimate the dose (D) using equation 1 for surfing.

$$D_{oral,\ surf} = I_{oral} \times 0.01 \times C_{ENT\ or\ FC} \qquad \textbf{Eq. 1}$$

$$p(ill)_{ENT,\ day} = [1 - \exp(-D_{ENT,\ oral} / k)] \times \Psi \qquad \textbf{Eq. 2}$$

$$p(ill)_{FC,\ day} = 1 - [1 + (D_{FC,\ oral} / N_{50}) \times (2^{1/\alpha} - 1)]^{-\alpha} \qquad \textbf{Eq. 3}$$

We evaluated the GI risks of surfing using 2 dose-response models:

1. Risk evaluation from exposure to ENT in dry & post-storm conditions applying the exponential dose-response model, Eq. 2 (9, 11)
2. Risk evaluation from FC in dry & post-storm conditions applying the Beta-Poisson model, Eq. 3 (11)

Results

A summary of original extracted ENT and FC data at each beach is shown in Table 1.

Table 1. Summary of data used.

County	Beach Site	Number of data available	
		Post-storm	Dry
Los Angeles	Malibu	17	80
	Santa Monica	16	74
	Venice Beach	14	95
	El Segundo	20	96
Orange	Newport Beach	120	358
	Laguna Beach	16	107
San Diego	San Diego	29	93
	Coronado	19	84

Exponential dose-response model with ENT

- There are higher occurrences of GI cases during post-storm than during dry condition (Figures 2).
- All of the studied beaches exceed the EPA guideline of 19 GI cases per 1000 people more frequently after rainfall than during dry weather (Figures 2 & 3).

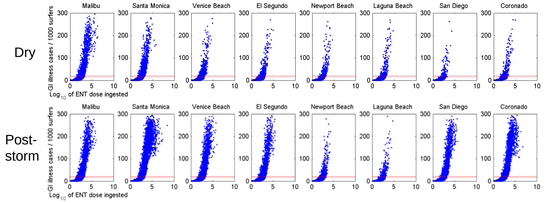
Beta-Poisson dose-response model with FC

- Some of the studied beaches exceed the EPA recreational health risk guideline more frequently after rainfall but others more frequently during dry weather (Figure 3).

Discussion

- There are significant differences in evaluating the dose-response GI risks of surfing using different FIB. The exponential model with ENT produces higher GI risks than does the Beta-Poisson model with FC.
- At most beaches, there are higher GI risks after rainfall than during dry condition.

Figure 2. Comparison of Monte Carlo simulation of GI cases per 1000 surfers based on the exponential dose-response model for enterococcus (ENT) at eight selected Southern California beaches during dry and post-storm conditions. The x-axis is the base-10 logarithm of ingested dose of ENT and the y-axis is the GI cases per 1000 surfers. The red line indicates the acceptable water recreational health risk of 19 GI cases per 1000 people set by U.S. EPA. The Monte Carlo simulation was run for 10,000 iterations. The top shows the results for dry condition, and the bottom shows the results for post-storm condition.



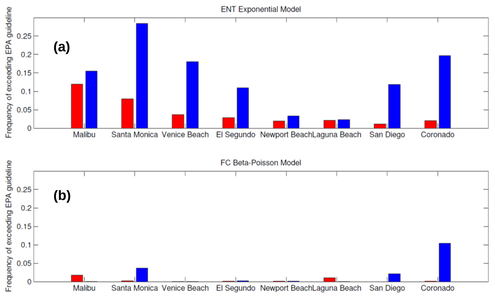


Figure 3. Frequency of GI illness risk exceeding the EPA guideline (19 GI cases per 1000 people) at selected Southern California beaches during dry (red bar) and post-storm conditions (blue bar). (a) Monte Carlo outputs using the enterococcus (ENT) exponential does-response model, and (b) Monte Carlo outputs using the fecal coliform (FC) Beta-Poisson does-response model.

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