QMRA as a Compliment to Epidemiologic Studies Estimating Bather Risk at Recreational Beaches

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The US EPA and WHO have set recreational water quality standards based on epidemiologic studies to protect human health at beaches. These studies have largely been limited to sewage-impacted sites and resources are unlikely to be available to assess the myriad of other impacted sites. Here we describe how quantitative microbial risk assessment (QMRA) can be used to assess unstudied pathogen sources in a systematic way to describe risk uncertainty. To illustrate the proposed QMRA comparison an illustrative example is provided focusing on the non-sewage example sources of seagulls and human shedders.

Research Objectives

1. Compare predicted risk of gastrointestinal (GI) illness from sewage impacted recreational water to non-sewage impacted water using QMRA.
2. Identify key uncertain pieces of information in the QMRA estimation of risk to inform future research.

Quantitative Microbial Risk Assessment (QMRA) with Monte Carlo sampling of uncertain parameters

1. Problem Formation

SOURCES

C. jejuni
Salmonella sp.

Norovirus C. jejuni, Giardia, Cryptosporidium sp. and Salmonella sp.

Norovirus, Giardia, Cryptosporidium sp. and Salmonella sp.

Reference pathogens

2. Monte Carlo Calculation of Pathogen Dose

The pathogen dose $\mu^{s}_{sp,}$ is calculated for ingestion of water with a fecal-indicator bacterial concentration C_{ENT} at the single sample enterococci (ENT) limit of 104 cfu 100mL^{-1}:

$$\mu^{s}_{sp} = \frac{C_{ENT} * F^{s}}{R^{s}_{ENT} * 100} * R^{s}_{sp} * p^{s} * I^{s} * V$$

S is the source sewage (SW), human shedder (H) and sea gulls (G)
F^{s} is the fraction of total ENT from source s
R^{s}_{ENT} is the ratio of the count of ENT to the mass of feces for gulls and human shedders (cfu/g) or to the volume of sewage (cfu/L)
V is the volume of water ingested (mL)
R^{s}_{sp} is the ratio of the count of pathogen species to the mass of feces for gulls and human shedders (cfu/g) or to the volume of sewage (cfu/L)
p^{s} is the fraction of human-infectious pathogen strains from source s
I^{s}_{sp} is the infection rate in population of source s

3. Probability of Gastro-intestinal Illness for Adults

The probabilities of gastro-intestinal illness are calculated using dose-response relationships from the literature with best parameter estimates provided in Table 2.

Table 1. Parameters used for calculation of pathogen dose from sources of sewage (Sw), human shedder (H), and seagull (G)

Parameter	S	Units	Uniform Distribution	Reference
Ratio ENT to source (R^{s}_{ENT})	Sw	cfu L^{-1}	$a = 1E7 \quad b = 1E8$	(Tschobanoglous et al., 2003)
	H	cfu g^{-1}	$a = 2E3 \quad b = 3E8$	(Slanetz and Bartley, 1957)
	G	cfu g^{-1}	$a = 1E6 \quad b = 1E8$	(Fogarty et al., 2003)
Ratio *C. jejuni* to source ($R^{s}_{C.j}$)	H	cfu g^{-1}	$a = 1E6 \quad b = 1E9$	(Hindiyeh et al., 2000)
	G	cfu g^{-1}	$a = 2E3 \quad b = 1E6$	(Lévesque et al., 2000)
Ratio *Salmonella* to source (R^{s}_{S})	Sw	cfu L^{-1}	$a = 3E0 \quad b = 1E3$	(Lemarchand, 2003)
	H	cfu g^{-1}	$a = 1E6 \quad b = 1E9$	(Hindiyeh et al., 2000)
	G	cfu g^{-1}	$a = 2E2 \quad b = 1E9$	(Lévesque et al., 2000)
Ratio *Cryptosporidium* to source (R^{s}_{C})	Sw	oocysts L^{-1}	$a = 5E-1 \quad b = 4E$	(Rose et al., 2004)
	H	oocysts g^{-1}	$a = 1E4 \quad b = 8E8$	(Okhuysen et al., 1999)
Ratio *Giardia* to source (R^{s}_{G})	Sw	cysts L^{-1}	$a = 7E0 \quad b = 1E4$	(Rose et al., 2004)
	H	cysts g^{-1}	$a = 1E4 \quad b = 8E8$	(Gerba, 2000)
Ratio *Norovirus* to source (R^{s}_{N})	Sw	genomes L^{-1}	$a = 9E2 \quad b = 3E7$	(Katayama et al., 2008)
	H	genomes g^{-1}	$a = 1E7 \quad b = 1E10$	(Ludwig et al., 2008)
Infection rate of *C. jejuni* ($I^{s}_{C.j}$)	H	NA	$a = 0.0064 \quad b = .01$	(Orange County 2008)
Infection rate of *Salmonella* (I^{s}_{S})	H	NA	$a = 0.0083 \quad b = .01$	(Orange County 2008)
Infection rate of *Cryptosporidium* (I^{s}_{C})	H	NA	$a = 0.0003 \quad b = .00$	(Orange County 2008)
Infection rate of *Giardia* (I^{s}_{G})	H	NA	$a = 0.0031 \quad b = .00$	(Orange County 2008)
Infection rate of *Norovirus* (I^{s}_{N})	H	NA	$a = 0.04 \quad b = .16$	(HMSO 2000)
Fraction of human-infectious pathogen strains (p^{s})	Sw	NA	1	NA
	G	NA	0.2	(Quessy and Messier, 1992)

Table 2. Parameter Inputs for Dose-Response

Pathogen	Units	Dose-Response	Reference
Campylobacter jejuni	cfu	Adult Beta-Poisson $P_{inf} = 1 - {}_1F_1(\alpha, \alpha+\beta, -\mu) = 1 - \sum_{n=0}^{\infty} \frac{(\alpha)_n}{(\alpha+\beta)_n} \frac{(-\mu)^n}{n!}$ $a = 0.145 \quad B = 7.59 \quad P_{illinf} = 0.2$	(Black et al., 1988)
Salmonella enterica serotype Bareilly	cfu	Gompertz $P_{inf} = 1 - \exp(-\exp(-\ln(a) + b\ln(u)))$ $\ln(a) = 11.68 \quad b = 0.82$	(Soller JA et al., 2007)
Cryptosporidium parvum	oocysts	exponential $P_{inf} = 1 - e^{-E(r)u} \quad E(r) = 0.09 \quad P_{illinf} = 0.7$	(EPA 2005)
Giardia intestinalis	cysts	exponential $P_{inf} = 1 - e^{-E(r)u} \quad E(r) = 0.0199 \quad P_{illinf} = 0.9$	(Perz et al., 1998; Rose et al., 1991)
Norovirus	genomes	$P_{inf} = 1 - {}_2F_1(\alpha, \frac{u(1-a)}{a}, \alpha+\beta, \frac{-a}{1-a})$ $\alpha = 0.04 \quad a = 0.0001 \quad \beta = 0.055$ $P_{illinf} = 1 - (1+\eta u)^{-r}$ $\eta = 2.55E-3 \quad r = -0.086$	(Teunis and Havelaar, 2000)

Results

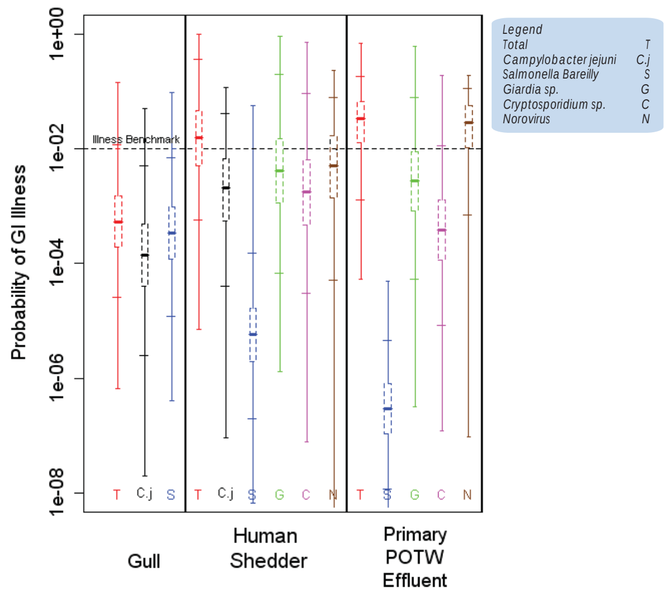

Figure 1. Comparison of predicted probability of gastro-intestinal illness for adults (median, interquartile range, 95% confidence interval and extremes) from accidental ingestion of recreation water containing fresh fecal contamination at 104 CFU/100mL ENT.

Table 3. Predicted median pathogen concentrations in recreational water

Source	*Campylobacter jejuni* (CFU/100mL)	*Salmonella enterica* (CFU/100mL)	*Giardia* (Cysts/100mL)	*Cryptosporidium* (Oocysts/100mL)	*Norovirus* (Genomes /100mL)
Sea Gull	1.0	2.5E3	NA	NA	NA
Human Shedder	3.1	3.5	1.2	1.0E-1	3.3E2
Primary POTW Effluent	NA	1.0E-1	9.0E-1	3.6E-1	2.7E3

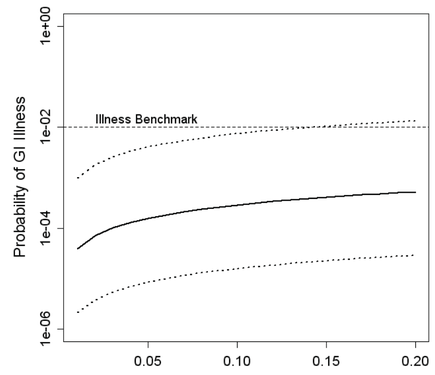

Figure 2. Sensitivity analysis of the predicted probability of gastrointestinal illness for adults (median and 95% confidence interval) from accidental ingestion of recreation water containing fresh gull fecal contamination at 104 CFU/100mL ENT to changes in the assumed fraction of total strains from gulls that are human infectious.

Conclusions

1. Using seagulls as an example non-sewage source, the upper 95% CI probability of illness from gulls for fecal indicator levels at the recreational standard of 104 cfu/100mL, assuming the fraction of human-infectious pathogenic strains from seagulls is 0.2, is greater than the illness benchmark of 0.01.
2. This risk is sensitive to the fraction of human infectious pathogens in animal feces. Since the human-infectious concentration of pathogens in non-human matter is not well characterized, the probability of illness from non-human sources may change and drop below the health benchmark with additional information on the content of animal feces.
3. Given the current high level of uncertainty in prediction probability of infection using QMRA, no difference can be concluded between the risk from a sewage impacted water and that of an exclusively seagull impacted water.

Future Work

- Modify approach to account for enterococci loads from beach sand and differences in persistence between pathogens and the fecal indicator in the environment
- Estimate risk to swimmers using field data and site specific parameters and compare results to ongoing epidemiologic study

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