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Estimation of diarrhoeal infection risk in parks and recreational areas after urban flooding

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Abstract: Urban cloudburst management may include intentional temporary storage of flood water in parks or other recreational areas. In cities with combined sewers this will expose the population to wastewater and increase the risk of diarrhoeal disease. We present an approach to estimate the risk of diarrhoeal disease after urban flooding of a green area by combining hydraulic modelling, an experimental flood simulation and quantitative microbial risk assessment (QMRA). The method allows the cloudburst manager to reduce unacceptable disease risks during the planning of cloudburst management or on existing facilities.

Keywords: Cloudburst management, Diarrhoeal disease, Quantitative Microbial Risk Assessment Urban flooding.

Background

Diarrhoeal disease is a global health problem that is considered unlikely to be solved soon, and the current positive development may be undermined by environmental changes that damage urban infrastructure. A large proportion of diarrhoeal diseases are caused by faecal-oral pathogens due partly to inadequate sanitation. WHO recommends a risk-based method to achieve safe sanitation systems (WHO 2014; 2016; 2018).

Most middle- and high-income countries have safe sanitary systems protecting against waterborne diarrhoeal diseases. However, the climate changes are expected to lead to increased frequency of heavy precipitation (Hoegh-Guldberg et al, 2018), causing increased probability of urban floods. In cities with combined sewers, the flood water will expose the population directly or indirectly to wastewater and pose a risk of diarrhoeal disease.

The cloudburst management in Danish cities may include intentional temporal storage of flood water in green recreational areas to reduce the need for drainage capacity. Staying in a green recreational area after a flood will increase the risk of diarrhoeal disease, rising several important questions. How high is the risk? Is it acceptable? What can be done to reduce the risk?

Here we present an approach to estimate the risk of diarrhoeal disease after urban flooding of a green area by combining hydraulic modelling, an experimental flood simulation and quantitative microbial risk assessment (QMRA). The method allows the cloudburst manager and authorities to reduce unacceptable disease risks during the planning of or on existing cloudburst management facilities.

Methods

The investigated exposure scenario is based on a flooding of Fælledparken in Copenhagen, Denmark that occurred on 2nd July 2011. Rain water mixed with wastewater flows into the park. Pathogens from the wastewater deposit on the grass.

A baby is playing on the grass after the flood, transferring pathogens from grass to mouth by licking its hands.

We coupled a one-dimensional sewer model (MIKE Urban), a 2D hydrodynamic surface model (MIKE21) and A/D modules to estimate the geographical distribution of the deposition of pathogens in the grass. To estimate the dose of pathogens ingested, we experimentally simulated a flood by adding a mixture of wastewater and drinking water to 0.86 m^2 grass patches (two exposed to sun, two in shadow and one control) and left it to settle before draining the water. Faecal indicators and selected pathogens were analysed in the wastewater, in the grass and on hands after touching the grass. The transfer of pathogens from hand to mouth was estimated based on literature. The pathogen doses (*Campylobacter jejuni*, Rota- and Norovirus, Hepatitis A, *Cryptosporidium parvum*, *Giardia duodenalis* and *E. coli* O157) were estimated by multiplying the deposition in the grass with literature values for the pathogens in raw wastewater and the fractions transferred from grass to hands and further to the baby´s mouth. The QMRA was performed in @Risk (Palisade) using dose-response relationships from peer reviewed literature. (References too numerous to cite here)

Results and discussion:

The model showed that 15% of the flooded part of the park was influenced by wastewater with an average deposition of $3.5 \cdot 10^{-5}$ m and a maximum deposition of 0.007 m.

In the experimental, simulated flooding we analysed the concentration of *E. coli*, parasites and MS2 in the grass and on the hands. The transfer of *E. coli* from grass to hands was typically 10% (Figure 1 and 2). The concentration of *E. coli* in the grass followed a log linear temporal decrease. Surprisingly there was no observable effect of exposure to sun. Two days after the experimental flood, the protozoan parasites could no longer be detected on the hands (data not shown).

The QMRA estimated a combined average probability of illness of 10^{-3} for a baby playing for 0.5 hours on the lawn right after the contaminated water has infiltrated or drained away (Table 1). The highest risk was associated with *Campylobacter*, Norovirus and *Cryptosporidium*.

The probability of illness decreased exponentially with a $T_{90\%}$ of 5.5 days (Figure 3). By prohibiting access to the most influenced 4% of the flooded area, the probability of illness will be reduced by approximately 50% (Figure 4).

We have established a methodology to estimate the probability of infection/illness after flooding of recreational areas with wastewater-influenced water. The risk after 30 min. play on the grass is lower than the risk generally accepted for recreational water but higher than the risk accepted for drinking water and higher than the acceptable burden of disease risk suggested by WHO.

When planning use of parks and green areas for cloudburst management, the manager or the responsible authorities can use the models to evaluate the risk and if found unacceptable, change the plans to reduce the risk or decide to implement interventions such as restriction of access or information to the public.

References:

Hoegh-Guldberg et al. 2018. *Impacts of 1.5ºC Global Warming on Natural and Human Systems.* In: *Global Warming of 1.5°C. An IPCC Special Report*

WHO 2014: *Quantitative risk assessment of the effects of climate change on selected causes of death*.

WHO 2016: *Sanitation safety planning.*

WHO 2018: *Guidelines on sanitation and health*

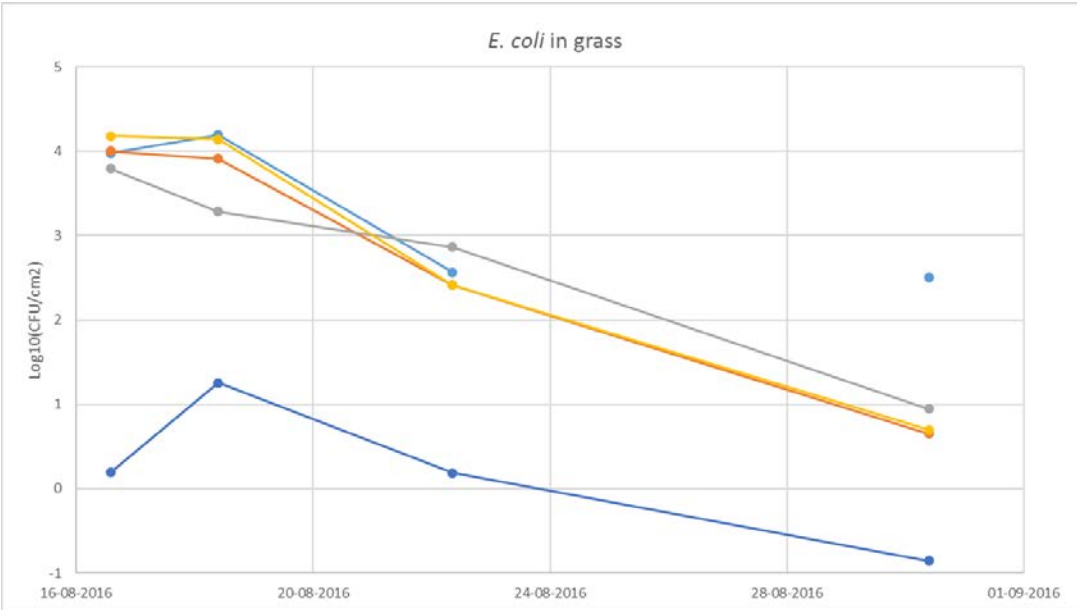

Figure 1: Concentrations of *E. coli* in the grass in the period after adding diluted waste water to the grass. Legend: Control: Dark blue; Lawn exposed to sun: light blue and orange; Lawn in Shadow: grey and yellow.

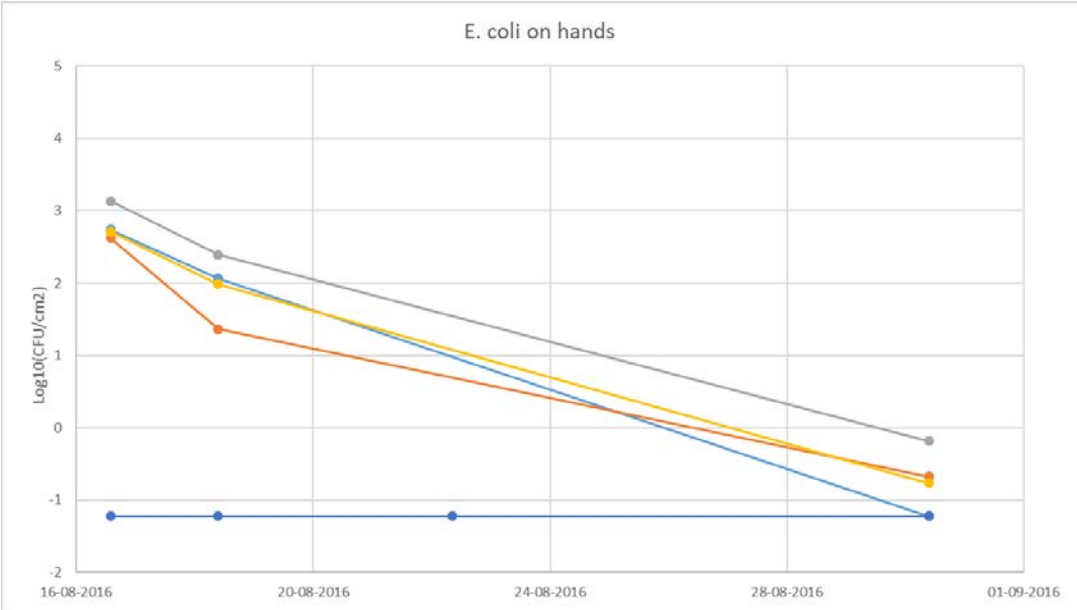

Figure 2: Concentrations of *E. coli* on hands in the period after adding diluted waste water to grass. Legend: Control: Dark blue; Lawn exposed to sun: light blue and orange; Lawn in Shadow: grey and yellow.

Table 1: Estimated average and 95-percentile probabilities of infection and illness caused by each analysed pathogen and as the combined probability for the seven pathogens at time zero**.**

	Combined	*Campylo bacter*	Norovirus	*Crypto sporidium*	*Giardia*	*E. coli* O157	Rotavirus	Hep. A virus
Infection								
Average	$1.4 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	$1.8 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$	$8.9 \cdot 10^{-6}$	$4.9 \cdot 10^{-6}$	$4.1 \cdot 10^{-6}$	$1.4 \cdot 10^{-10}$
95%-tile	$5.7 \cdot 10^{-3}$	$3.6 \cdot 10^{-3}$	$5.8 \cdot 10^{-5}$	$9.0 \cdot 10^{-4}$	$4.5 \cdot 10^{-5}$	$3.7 \cdot 10^{-6}$	$9.7 \cdot 10^{-6}$	$7.4 \cdot 10^{-10}$
Illness								
Average	$9.4 \cdot 10^{-4}$	$6.8 \cdot 10^{-4}$	$4.0 \cdot 10^{-5}$	$1.7 \cdot 10^{-4}$	$7.2 \cdot 10^{-6}$	$4.9 \cdot 10^{-6}$	$4.1 \cdot 10^{-6}$	$1.4 \cdot 10^{-10}$
95%-tile	$4.0 \cdot 10^{-3}$	$2.4 \cdot 10^{-3}$	$1.3 \cdot 10^{-5}$	$9.0 \cdot 10^{-4}$	$3.7 \cdot 10^{-5}$	$3.7 \cdot 10^{-6}$	$9.7 \cdot 10^{-6}$	$1.4 \cdot 10^{-10}$

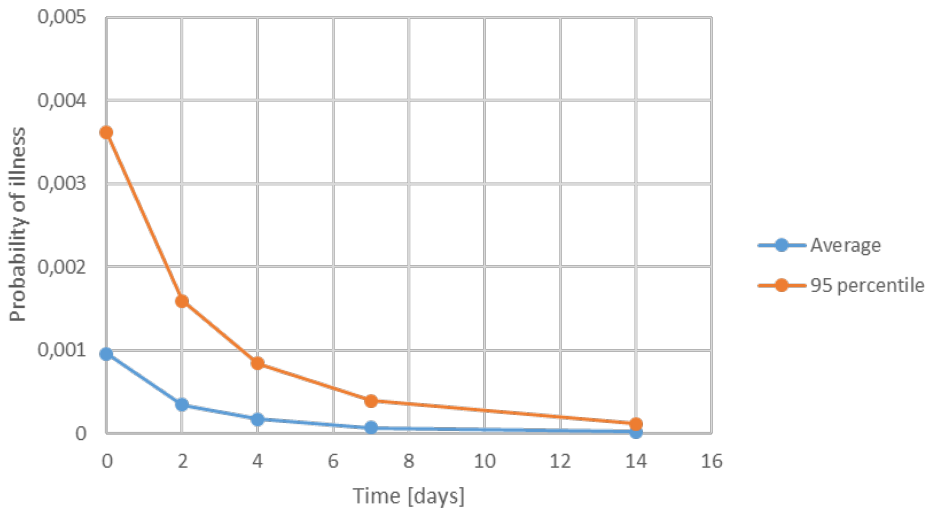

Figure 3: Average and 95 percentiles of the probability of illness combined from the probabilities from each of the seven pathogens included in the QMRA.

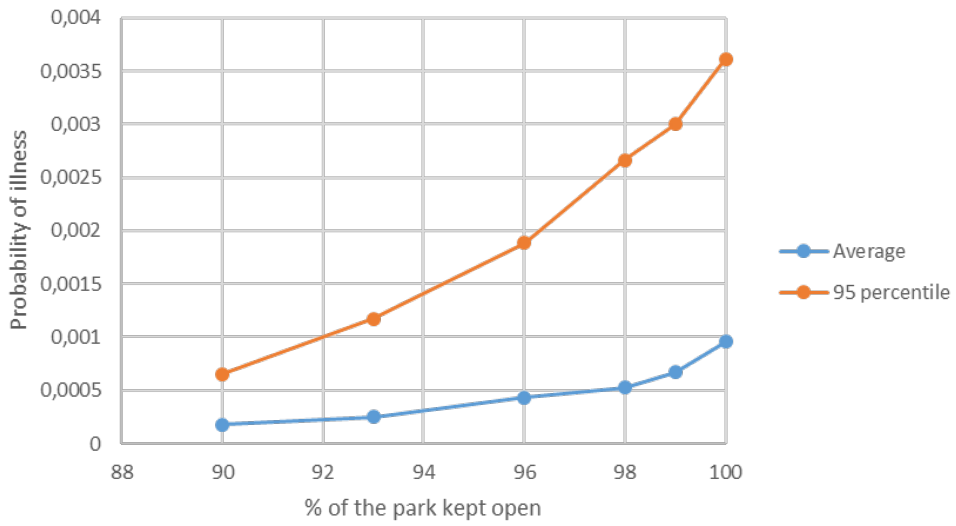

Figure 4: Effect of intervention by restricting access to the most polluted areas of the park on the average and 95 percentiles of the probability of illness combined from the probabilities from each of the seven pathogens included in the QMRA