Water Research

Volume 54, 1 May 2014, Pages 254-261

Health risk assessment for splash parks that use rainwater as source water

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https://doi.org/10.1016/j.watres.2014.02.010

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Highlights

- A QMRA was performed for splash parks that use rainwater as source water.
- Observations on site were used to quantify exposure volumes for inhalation and ingestion.
- Data for *L. pneumophila* was used to quantify infection risks for exposure through inhalation.
- Data for *C. jejuni* was used to quantify infection risks for exposure through ingestion.
- Using rainwater as source water for splash parks may pose a risk for public health.

Abstract

In the Netherlands, rainwater becomes more and more popular as an economic and environmentally sustainable water source for splash parks, however, the associated public health risk and underlying risk factors are unknown. Since splash parks have been associated with outbreaks of infectious diseases, a quantitative microbial risk assessment was performed using Legionella pneumophila as a target pathogen to quantify the risk of infection for exposure due to inhalation and Campylobacter jejuni for ingestion. Data for *L. pneumophila* and *C. jejuni* concentrations in rainfall generated surface runoff from streets were extracted from literature. Data for exposure were obtained by observing 604 people at splash parks, of whom 259 were children. Exposure volumes were estimated using data from literature to determine the volume of exposure through inhalation at 0.394 μL/min (95% CI-range 0.0446–1.27 μL/min), hand-to-mouth contact at 22.6 μL/min, (95% CI-range 2.02–81.0 μL/min), ingestion of water droplets at 94.4 μL/min (95% CI-range 5.1–279 μL/min) and ingestion of mouthfuls of water at $21.5 \cdot 10^3$ μL/min (95% CI-range $1.17 \cdot 10^3$–$67.0 \cdot 10^3$ μL/min). The corresponding risk of infection for the mean exposure duration of 3.5 min was $9.3 \cdot 10^{-5}$ (95% CI-range 0–$2.4 \cdot 10^{-4}$) for inhalation of *L. pneumophila* and $3.6 \cdot 10^{-2}$ (95% CI-range 0–$5.3 \cdot 10^{-1}$) for ingestion of *C. jejuni*. This study provided a methodology to quantify exposure volumes using observations on site. We estimated that using rainwater as source water for splash parks may pose a health risk, however, further detailed quantitative microbial analysis is required to confirm this finding. Furthermore we give insight into the effect of water quality standards, which may limit infection risks from exposure at splash parks.

Introduction

Splash parks are often located in shopping areas or play grounds. They are popular features that encourage many children to play with water. Splash parks use water that is typically stored in an underground reservoir or surge chamber and is sprayed into the air; after it hits the ground, it flows back to the reservoir through floor drains. Although almost all splash parks incorporate some form of disinfection, many show poor water quality through poor design or poor maintenance (Kebabjian, 2003). Thus, splash parks have been associated with outbreaks of infectious diseases, including *Legionella* (Hlady

et al., 1993, Palmore et al., 2009, Haupt et al., 2012, Correia et al., 2001), *Cryptosporidium* and *Giardia* (Eisenstein et al., 2008, Anonymous, 2000, Anonymous, 1999), *Shigella* (Fleming et al., 2000, Bancroft et al., 2010), *Salmonella* (Andión Campos, 1995, Molinero et al., 1998, Usera et al., 1995), *Leptospira* (Cacciapuoti et al., 1987), and noroviruses (Hoebe et al., 2004).

People may be exposed to waterborne pathogens in splash park through inhalation, ingestion and dermal contact. Inhalation of aerosols causes deposition of water in the respiratory tract (Heyder et al., 1986) and may cause allergic reactions (Douwes et al., 2003). If pathogens are present in water of splash parks, inhalation may cause infectious diseases such as pneumonia due to *Legionella pneumophila* (Fields et al., 2002). Ingestion of water, whether intended (by swallowing mouthfuls of water) or unintended (through getting water droplets in the mouth or through hand-to-mouth contact) can cause gastroenteritis though infection with enteric pathogens such as norovirus, rotavirus, *Campylobacter*, *Giardia* or *Cryptosporidium*, and may cause other severe illnesses such as hemolytic uremic syndrome (Keene et al., 1994) or Gullain-Barré syndrome (McCarthy and Giesecke, 2001). Finally, dermal contact (skin and mucous membranes of nose, ears and eyes in contact with the water) can result in infections such as wound infections due to *Aeromonas hydrophila* (Semel and Trenholme, 1990), otitis externa due to *Pseudomonas aeruginosa* (Van Asperen et al., 1995), or conjunctivitis due to adenoviruses (Crabtree et al., 1997).

Quantitative microbial risk assessment (QMRA) is a tool to quantify health risks and to get insight into measures that can prevent outbreaks (World Health Organization, 2011). A QMRA requires information on the concentration of pathogens in the matrix, the fate and behavior of pathogens, the volume of water to which people were exposed, and the dose–response relation for the pathogen.

Because harvested rainwater has been widely regarded as a sustainable source for water (re)use in urban areas and for recreational purposes, it is often used as a source water of splash parks (De Man et al., 2014b). Pathogens may be present in rainwater dependent on weather conditions such as rainfall intensity and temperature (Schets et al., 2010, Kaushik et al., 2012). Furthermore, the atmospheric deposition of airborne microorganisms (Evans et al., 2006), the (rooftop) runoff of fecal depositions of birds and other mammals (Ahmed et al., 2012, Fewtrell and Kay, 2007), and the growth or decay of micro-organisms in collected rainwater may influence the presence of pathogens in rainwater (Ahmed et al., 2014). Pathogens may also be introduced into water of splash parks by people, dogs, birds and other animals upon contact with the water (Hoebe et al., 2004).

To be able to quantify the public health risk of splash parks that use rainwater as their source water, an exposure assessment was performed using field observations. The generated exposure data were used to determine exposure volumes and infection risks for inhalation and ingestion by a QMRA approach. The QMRA was performed with Monte Carlo simulations to provide a range of uncertainties in infection risks.

Section snippets

Hazard identification

People are exposed to the water of urban splash parks through ingestion, inhalation and dermal contact. To estimate the public health risks, these exposure routes were used to choose model organisms that (I) were pathogens of concern in situations where people were exposed to water, (II) were present in rainwater and (III) showed a dose–response relation. Based on these criteria, *L. pneumophila* was chosen to model inhalation and *Campylobacter jejuni* for ingestion. These pathogens were preferred …

Results

A QMRA was performed to calculate the risk of infection inherent to exposure to splash parks using rainwater as their source. To quantify the risk of infection, *L. pneumophila* and *C. jejuni* were selected as target pathogens. The concentration of *L. pneumophila* in rainwater was described by a Gamma distribution with r=0.045 and λ=26,000 with an average concentration of *L. pneumophila* of 1200 cfu/l. The concentration of *C. jejuni* in rainwater was described by a Gamma distribution with r …

Hazard Identification

This study estimated the public health risk of splash parks that use rainwater as their source water. *L. pneumophila* and *C. jejuni* have been chosen to determine the risk of infection for inhalation and ingestion at splash parks. The target pathogen *L. pneumophila* that is used to quantify health risks after inhalation, can grow and become more virulent at water temperatures above 25 °C. The growth of *Legionella* was not incorporated into our model, because water temperatures above 25 °C require …

Conclusion

This study showed that exposure to splash parks that use rainwater as their source water can cause an infection risk. While at this moment, splash parks do not have to meet any criteria for water quality and/or design, this study should give rise to debates concerning the need for such guidelines. The scenario analyses gives information about infection risks for specific concentrations of pathogens in their source water. This information is valuable in terms of the insight it provides into the …

Disclosure

The authors declare they have no competing financial interests. …

Acknowledgments

The authors are grateful to Mr. R. Sakamoto who provided raw data of *Legionella* in rainwater samples. The research was funded by STOWA (Dutch Foundation for Applied Water Research), RIONED (Dutch Centre of Expertise in Sewer Management and Urban Drainage), the Municipalities of Groningen, Nijmegen, Rotterdam and Utrecht, and the Water Boards 'Noorderzijlvest', 'Hoogheemraadschap de Stichtse Rijnlanden', 'Hoogheemraadschap Delfland', 'Waterschap Hollandse Delta' and 'Hoogheemraadschap Schieland …

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> ...Although the pool exposure model is different than that used in the current study, the de Man et al. (2014a) work supports that pool risks can be potentially high compared to other exposure routes. The current QMRA did not consider ingestion of mouthfuls of water as in de Man et al. (2014a) models due to the difference between active splash parks and private pools. However, exposures to pool water could potentially be higher in some circumstances if mouthfuls of water are considered....

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