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Risk factors and monitoring for water quality to determine best management practices for splash parks

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ABSTRACT

Splash parks have been associated with infectious disease outbreaks as a result of exposure to poor water quality. To be able to protect public health, risk factors were identified that determine poor water quality. Samples were taken at seven splash parks where operators were willing to participate in the study. Higher concentrations of *Escherichia coli* were measured in water of splash parks filled with rainwater or surface water as compared with sites filled with tap water, independent of routine inspection intervals and employed disinfection. Management practices to prevent fecal contamination and guarantee maintaining good water quality at splash parks should include selection of source water of acceptable quality.

Key words | best management practices, fecal contamination, gastroenteritis, interactive water features, source water, water quality

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INTRODUCTION

No consistent requirements for water treatment in splash parks exist. In the majority of the cases, splash parks are unregulated and subject neither to construction review nor to routine inspection by public health officials. Splash parks have been associated with outbreaks of bacterial, parasitic and viral diseases (Cacciapuoti *et al.* 1987; Hoebe *et al.* 2004; Eisenstein *et al.* 2008). Splash parks may comprise of water sprays, dancing water jets, waterfalls, dumping buckets, shooting water cannons, or similar features that encourage children to play with water. Typically, a splash park makes use of a small amount of water that is recirculated, while the water may come into contact with many children when bather densities are high.

The water in the reservoir may contain contaminants originating from the source water itself, or from people using the splash park for bathing purposes (Hoebe *et al.* 2004), or from runoff flowing into its reservoir possibly including animal feces (De Man *et al.* 2014b). These contaminants may include human pathogenic microorganisms, such as enteric bacteria, parasites and viruses. Pathogens can be removed or inactivated by disinfection, provided that the disinfection systems are well designed, operated and maintained. Disinfection technology at splash parks usually includes high-flow sand filtration, combined with ultraviolet disinfection or chlorination.

To be able to protect public health, risk factors associated with fecal contamination were identified for splash parks. *Escherichia coli* levels were measured in water during routine inspections at seven splash parks as a proxy for fecal contamination. Characteristics and management practices were recorded for each splash park. In addition, dynamics in fecal contamination were monitored over 4 weeks to evaluate the efficacy of the proposed best water quality management practices for splash parks.

METHODS

Description of sampling locations

Seven splash parks in the Netherlands were sampled from May until September 2011. These locations were selected based on information from local authorities about operators who are willing to participate. The splash parks differed in

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specific characteristics, including source water, disinfection system, the runoff of rainwater into their reservoir, routine inspection intervals, actions performed during routine inspection and the size of their reservoirs (Table 1). The routine inspection interval was defined as the regular period after which the operator performed some actions to maintain good water quality at the splash park. The routine inspection intervals varied from 1 week up to 6 months (Table 1).

Assessment of water quality

The presence of *Escherichia coli* indicates fecal contamination and the possible presence of enteric pathogens in the water (World Health Organization 2011). Therefore, this indicator was measured to determine water quality. Water samples were taken during two routine inspection intervals at each splash park, yielding 5–10 samples per water feature. Water samples of 40, 10, 1 and 0.1 ml were analyzed in duplicate within 24 hours of sampling for *E. coli*. *E. coli* was enumerated using membrane filtration followed by the Rapid Test on Tryptone Soy Agar (996292; Oxoid, Wesel, Germany) and Tryptone Bile Agar (806567; Oxoid) according to ISO9308-1 (ISO 2000).

The measurements were assessed according to standards for *E. coli* given in the European Bathing water Directive 2006/7/EC (CEC 2006) because there are no requirements for the water quality of splash parks and because exposure volumes through ingestion may be similar as compared with swimming (De Man *et al.* 2014a). According to Directive 2006/7/EC good water quality should not exceed 1,000 colony forming units (cfu) *E. coli* per 100 ml (CEC 2006). At locations where the water quality of the splash parks was poor, the operator of the splash park was asked to drain the reservoir, to clean it using a pressure washer and to disinfect it with chlorine. Subsequently, measurements were repeated to determine the fecal contamination during 4 weeks.

Statistical analyses

The maximum likelihood method was used to estimate the concentration of *E. coli* in the undiluted sample, according to the method of Schijven *et al.* (2011).

RESULTS AND DISCUSSION

Fifty-one samples were taken at seven locations. *E. coli* was detected at all locations (Figure 1). Water quality at three splash parks (splash parks 5, 6 and 7) exceeded 1,000 *E. coli* cfu/100 ml. These splash parks, filled with rainwater or surface water, were found to have substantially higher concentrations of *E. coli* in the water than sites that were filled using tap water and where runoff does not drain into the reservoir (splash parks 1, 2, 3 and 4). These higher concentrations could be expected, since rainwater and surface water usually contain *E. coli* (Ahmed *et al.* 2011), while the absence of *E. coli* from 100 ml tap water in the Netherlands is required by law (Dutch Government 2011). Our

Table 1 | Description of splash parks

	Source water	Disinfection	Does rainwater runoff fill the reservoir?	Routine inspection interval	Actions performed during routine inspection by operator	Size of reservoir (m^3)
1	Tap water	Manually dosing of chlorine	No	1 week	Dosing of chlorine	2
2	Tap water	Manually dosing of chlorine	No	1 week	Dosing of chlorine	2
3	Tap water	High-flow sand filtration + UV	No	2 weeks	Backwashing SF	4
4	Tap water	High-flow sand filtration + UV	No	4 weeks	Backwashing SF	4
5	Rainwater	High-flow sand filtration + chlorine dosing by pump	Yes	2 weeks	Backwashing SF checking the functioning of the pump that doses chlorine	3
6	Local surface water	Manually dosing of chlorine	Yes	4 weeks	Dosing chlorine	16
7	Local surface water	UV	Yes	6 months	Change of the UV-lamp	30

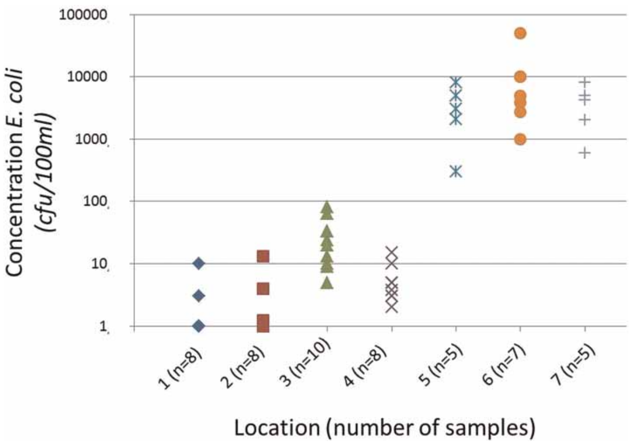

Figure 1 | Estimated concentrations of *E. coli* (colony forming units (cfu)/100 ml) in water of splash parks.

measurements showed that, in contrast with splash parks replenished with tap water, splash parks using local surface water or allowing rain water runoff cannot be disinfected. This is consistent with Johnson *et al.* (1991), who stated that decontamination is more effective when applied to a product of good microbial quality. This means that the trend to use rainwater or surface water as source water in fountains, splash parks or other water features is undesirable from the perspective of public health, under the assumption that *E. coli* is a good indicator for the presence of human pathogens (World Health Organization 2011).

Irrespective of the type of disinfection applied at a location (ultraviolet radiation (UV)/chlorination/high flow sand filtration), the type of disinfection did not improve water quality adequately. Apparently, none of the employed disinfection systems removed or inactivated bacteria such as *E. coli* from the water below the detection method of our analyses. Possible explanations for the failure to inactivate *E. coli* include: (1) that the dose of UV fluence was too low; (2) the turbidity of the water absorbed the UV fluence; (3) the dose of chlorine was insufficient; or (4) chlorine reacted with organic and inorganic compounds and was not available to inactivate *E. coli* (Deborde & von Gunten 2008). Even though *E. coli* was absent in five of the 51 samples, the water quality may still be unacceptable because the employed disinfection methods may be able to efficiently remove indicator bacteria, but not pathogenic viruses, parasites, spores and viable, but non-culturable, bacteria (Koivunen & Heinonen-Tanski 2005), such as noroviruses, *Cryptosporidium*, *Clostridium* and *Legionella pneumophila*. On the other hand, assuming 1 g of feces contaminating a reservoir filled with 4 m^3 of tap water (10^8 cfu/gram /4 m^3) would lead to a concentration of 2,500 cfu *E. coli* per 100 ml in water, the measured concentrations (below 10 cfu *E. coli* per 100 ml at splash parks 1, 2 and 4) were low compared to this value and showed that the employed disinfection may have inactivated the bacteria present as a result of the hypothetical fecal contamination event.

Further comparison of locations showed that the size of the reservoir, the interval between routine inspections, and the actions performed during those inspections, did not influence the levels of fecal contamination. The results did not show any substantial increase or decrease in the fecal contamination of splash parks (data not shown). This implied that, despite all efforts of an operator of a splash park to prevent contaminations of the water, the design of a splash park (i.e. the choice of source water and prevention of runoff flowing into the reservoir) influenced the fecal contamination of a splash park the most.

The water quality at locations 5–7 was poor and the operators of these sites were asked to clean and disinfect the reservoirs. The operator of location 5 consented and as Figure 2 shows, water quality measurements before and after cleaning and disinfecting the reservoir showed that fecal contamination, absent directly after the cleaning and the refilling of the reservoir with tap water, returned within 4 weeks. One explanation for this might be contamination brought in by people using the fountains for bathing. However, this was also the case for splash parks 1–4.

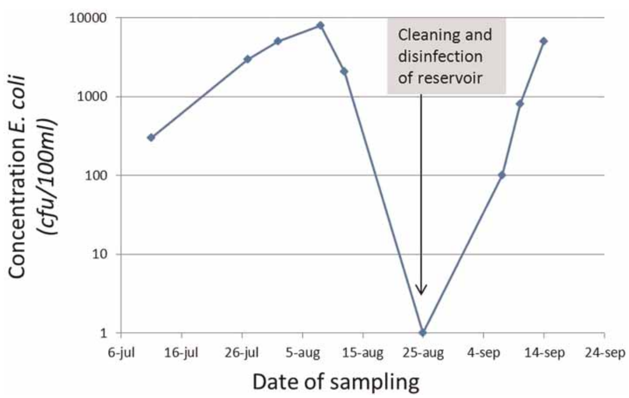

Figure 2 | Estimated concentrations of *E. coli* (cfu/100 ml) at location 5, before and after cleaning and disinfection of the reservoir.

A more likely explanation is that the runoff of rainwater in the reservoir increased the fecal contamination of the water and exceeded the capacity of the disinfection technology.

Three of seven splash parks showed a poor water quality, however, our study results may have been biased by the fact that samples were only taken at splash parks where operators were willing to participate. The three splash parks with poor water quality were found to be fecally contaminated by *E. coli* in similar concentrations detected at splash parks where disease outbreaks have occurred (Jones *et al*. 2006; Slater *et al*. 2006). A recent study has shown that signage and hygiene attendants did not adequately limit non-hygienic behaviors at splash parks (Nett *et al*. 2010). Furthermore, it is likely that especially vulnerable subpopulations (children, pregnant women or elderly) (Gerba *et al*. 1996) are exposed to splash parks and may be at greater risk. Therefore, to prevent outbreaks, local governments, together with public health departments and engineers, should consider the risk of exposure to water in splash parks. To guarantee good water quality, three best management practices could be employed: (1) the use of tap water as source water; (2) avoidance of rainwater runoff onto the reservoir; and (3) the use of disinfection technology to prevent recontamination. These best management practices would greatly improve the water quality of splash parks and could prevent outbreaks of infectious diseases.

CONCLUSION

The study showed that splash parks using tap water as source water have better water quality than splash parks using rainwater or surface water as source water. The disinfection systems in use are able to disinfect fecal contaminations in tap water, but are unable to disinfect rainwater or surface water. This strongly suggest that, from the perspective of public health, neither rainwater nor surface water should be recycled as the source water for fountains, splash parks or other water features. This needs to be taken into account by policy makers in the preparation of legislation for splash parks and should inform architects and engineers designing splash parks.

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