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ORIGINAL ARTICLE

Microbiological water quality and derived health risks from exposure to ornamental water fountains in the city of Hannover

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Abstract

Ornamental fountains are attractive urban infrastructures helping cities to cope with global warming, as water sprays have great cooling effects due to evaporative properties; however, exposure to microbiologically impaired water from ornamental fountains during recreational activities may result in adverse health outcomes for the exposed population. This study assesses the microbial water quality of four ornamental water fountains (Blätterbrunnen, Körtingbrunnen, Klaus–Bahlsen–Brunnen, and Marstallbrunnen) and performs a quantitative microbial risk assessment (QMRA) for children using *Escherichia coli*, Enterococci, and *Salmonella* to quantify the probability of gastrointestinal illnesses and *Pseudomonas aeruginosa* to quantify the risk of dermal infections. Samples were collected fortnightly in two campaigns in 2020 and 2021 and processed to determine bacterial concentrations. Data on exposure time were obtained during field observations on the selected fountains; a total of 499 people were observed of which 30% were children. Mean bacterial concentrations ranged from 1.6×10^1 to 6.1×10^2 most probable number (MPN)/100 mL for *E. coli*, 1.2×10^1–1.2×10^3 MPN/100 mL for Enterococci, 8.6×10^3–3.1×10^5 CFU/100 mL for *Salmonella*, and 2.5×10^3–3.2×10^4 MPN/100 mL for *P. aeruginosa*. The results of the QMRA study showed that the USEPA illness rate of 36 NEEAR-gastrointestinal illnesses/1000 was exceeded for Enterococci at the Körtingbrunnen, Klaus–Bahlsen–Brunnen, and Marstallbrunnen fountains and for *Salmonella* and *P. aeruginosa* at the Körtingbrunnen fountain, suggesting that exposure to microbiologically contaminated water from ornamental fountains may pose a health risk to children. The scenario analysis shows the importance of keeping low bacterial concentrations in ornamental fountains so that the risk of illness/infection to children does not exceed the USEPA illness rate benchmark.

KEYWORDS
health risks, ornamental fountains, QMRA, risk of illness/infection

1 | INTRODUCTION

Besides offering esthetic properties and recreational opportunities to their surroundings, ornamental fountains play a key role in enhancing human well-being and creating refreshing microclimates thanks to evaporative cooling processes (Seputra, 2018). Different water sources, such as groundwater, rainwater, and surface or tap water, can be used to fill up these water features. Many of the ornamental fountains in the city of Hannover are fed by the public drinking water supply, where water is constantly recirculated through pumps after being sprayed into the air (Freyer & Hanning, personal communication, June 5, 2020). These water features encourage people, especially children, to have direct contact with the water by playing, walking through, and/or touching the water (Man, Bouwknegt, et al., 2014).

Microbiological pollution of ornamental fountains fed with drinking water can occur through human and animal contact with water, runoff from paved surfaces, or growth of microorganisms in water, posing an emerging risk of infection/illness to the individuals exposed to the water through ingestion, inhalation, and dermal contact (Man, Heederik, et al., 2014). Fecal indicator bacteria, such as *Escherichia coli* and Enterococci, are commonly used as indicators to identify the potential presence of pathogenic microorganisms, which can cause gastrointestinal infection (Modrzewska et al., 2019). Savill et al. (2001) analyzed different water systems in New Zealand and found *Campylobacter* spp. in different concentrations. Additionally, during the summer months of 2018 and 2019, the number of human infections associated with *Vibrio* spp. in Germany increased greatly (Brehm et al., 2021). *Listeria monocytogenes* is also of concern as it is ubiquitous in the environment and can form biofilms, and the presence of *Pseudomonas aeruginosa* in water can result in skin rashes such as folliculitis when there is dermal exposure (Roser et al., 2015), making all these bacteria of interest for our study. *Legionella*-related illness can occur when contaminated water is aerosolized and inhaled. However, it was not included in our study because the inhalation exposure route was not considered. Therefore, maintaining safe water quality in ornamental fountains as well as developing a risk analysis has become an important issue to be addressed (Man, Bouwknegt, et al., 2014). In Germany, the Verein Deutscher Ingenieure e.V. (VDI 6022) has established guidelines for the planning, construction, and operation of fountains and water walls in public buildings; nevertheless, there are no specifications on hygienic requirements for fountains and water features in public spaces.

Quantitative microbial risk assessment (QMRA) is one of the tools used to quantify the health risks caused by human exposure to waterborne pathogens (Haas et al., 2014; Ortells Sales, 2015). A QMRA study requires several sources of data, such as microorganism concentration (e.g., most probable number [MPN]/100 mL), exposure rates (e.g., mL/min), exposure duration (e.g., min/day), and dose–response model of the microorganism of interest. Due to the lack of studies focusing on these water features, there is limited exposure-data information regarding low water-contact recreational activities taking place in ornamental fountains. Moreover, temporal and spatial variability of water contact and bacterial concentrations are also important factors that make it difficult to relate recreational water exposure with specific health outcomes (Sunger & Haas, 2015). QMRA allows testing different scenarios and obtaining insights regarding measures to be applied to prevent outbreaks of infectious illnesses (Ortells Sales, 2015).

The aims of this study were (a) to determine the presence of potentially pathogenic bacteria in ornamental fountains fed with drinking water, (b) to perform a QMRA of the selected ornamental fountains for the chosen reference bacteria, and (c) to develop a scenario analysis and compare how different bacterial concentrations affect the risk of illness and infection for children.

2 | MATERIALS AND METHODS

2.1 | Sampling locations

For this study, we selected four ornamental water fountains in Hannover, each one with different architectures. These fountains are filled with fresh drinking water at the beginning of operations every year (around mid-April), which is continuously recirculated until the end of operations (mid-October); only when the water level drops down due to evaporation or high sediment content, it is refilled with fresh drinking water (Freyer & Hanning, personal communication, June 5, 2020). All these fountains are located within the city center and have open access to the public.

The Blätterbrunnen fountain is located a few meters from Kröpke within a busy shopping area in a pedestrian street. The water reaches the top of the built-in sculpture through four vents, and then, it flows downward and is stored in the retention basin until the water level reaches the collection channel. When water is recirculated, coarse dirt is retained in a grid, and chlorine and algaecide are manually dosed according to need (Figure 1a) (Freyer & Hannig, 2020).

The Klaus–Bahlsen–Brunnen fountain, located in an open area in front of the new City Hall, is designed with two pressure jets forming water columns that reach around 3 m height; once it hits the ground, water is collected by a gutter covered with a thick grid and stored shortly in a central narrow channel where the manual dosage of chlorine is made if needed before being recirculated (Figure 1b) (Freyer & Hannig, 2020).

The Körtingbrunnen fountain, located in a residential neighborhood of the List district, is surrounded by many cafes, restaurants, shops, and a playground. It is formed by five stainless steel head figures on top of a few brick stairs that continuously spout water. Water flows over the stairs and is collected by a channel covered by a grid that retains thick dirt; this fountain does not have a storage facility; thus, water is immediately recirculated (Figure 1c) (Freyer & Hannig, 2020).

The Marstallbrunnen fountain is found in a busy open plaza in the city center, surrounded by trees, restaurants, and cafes. Here, water is jetted reaching different heights and then hitting the ground. Afterward, water flows washing down the paved area and is collected, filtered, and disinfected in a retention basin before being recirculated. This is the only fountain with digital control of pH and automatic monitoring and dosage of chlorine (Figure 1d) (Freyer & Hannig, 2020).

2.2 | Health risk assessment

The QMRA approach was used to assess the risks posed by microbial agents and obtain the statistical probability of an adverse health outcome. This approach integrates a wide scientific knowledge about microorganisms, such as concentrations and behavior in water, routes and amounts of exposure to humans, and probable health outcomes from

FIGURE 1 Ornamental fountains selected in Hannover city, Germany a) Blätterbrunnen, b) Klaus-Bahlsen-Brunnen, c) Körtingbrunnen, d) Marstallbrunnen. *Source*: Own pictures.

exposure. With this information, a single assessment is performed, allowing a proper management of the risk (CAMRA, 2020a; WHO, 2016).

The main structure of the QMRA adopted in the present study consisted of four steps. First, *hazard identification* (Section 2.2.1), where the bacteria of interest are identified, as well as the illnesses caused by them, the transmission routes, and probable health outcomes. Second, in the *exposure assessment* step (Section 2.2.2), the bacterial numbers present in a single-exposure event are quantified. For the third step, *health effect assessment* (Section 2.2.3), the corresponding dose–response models are applied to each bacterium depending on the sought outcome (infection, illness, or death), and in the last step, *risk characterization* (Section 2.2.4), an estimate of the risk is obtained (Ortells Sales, 2015; WHO, 2016). A summary of the steps carried out for the QMRA study, their outcome, and the sections where each step is further described are presented in Figure 2.

Given that most of the population directly exposed to the water in the studied locations were children, the present study assesses the health risk posed by ornamental fountains to children.

2.2.1 | Hazard identification

Sample collection and microbiological water quality analysis

Sampling consisted of fortnightly grab samples taken in two campaigns; the first campaign took place from June 29 until September 21, 2020, and the second was held from May 10 until October 4, 2021. A total of 13 grab samples were taken at the Blätterbrunnen, whereas 10 grab samples were taken at the Körtingbrunnen, Klaus–Bahlsen–Brunnen, and Marstallbrunnen.

For the water quality analysis, the following bacteria were analyzed: *E. coli*, Enterococci, *Salmonella*, *Vibrio* spp.*,* *L. monocytogenes, Campylobacter* spp., *and P. aeruginosa*. Around 1 L of water was collected from each fountain for lab analysis; after collection, samples were stored at 4°C and analyzed within 24 h. From the 1 L sample, 300 mL were used to determine concentrations of viable Enterococci, *E. coli*, and *P. aeruginosa* using the IDEXX test kits, Enterolert, Colilert, and Pseudalert, respectively, according to the manufacturers' specifications (IDEXX Canada, ASTM Method #D6503-99). Water samples (diluted with distilled water when needed) were used; in sterile bottles (Carl Roth, Karlsruhe), 100 mL water sample was poured; then, the reagent of Enterolert/Colilert/Pseudalert was added and shaken until dissolved. The solution was poured in a Quanti-Tray 2000, sealed, and then incubated for 24 h at 41, 35, and 38°C for Enterococci, *E. coli*, and *P. aeruginosa*, respectively. After incubation, the fluorescent wells in the Quanti-Tray 2000 were counted under UV light to estimate the MPN of each bacterium per 100 mL (IDEXX Laboratories, 2019).

For *Salmonella* and *Vibrio* spp., 100 μL of sample was pipetted on agar plates (in some cases, a 10-fold dilution was

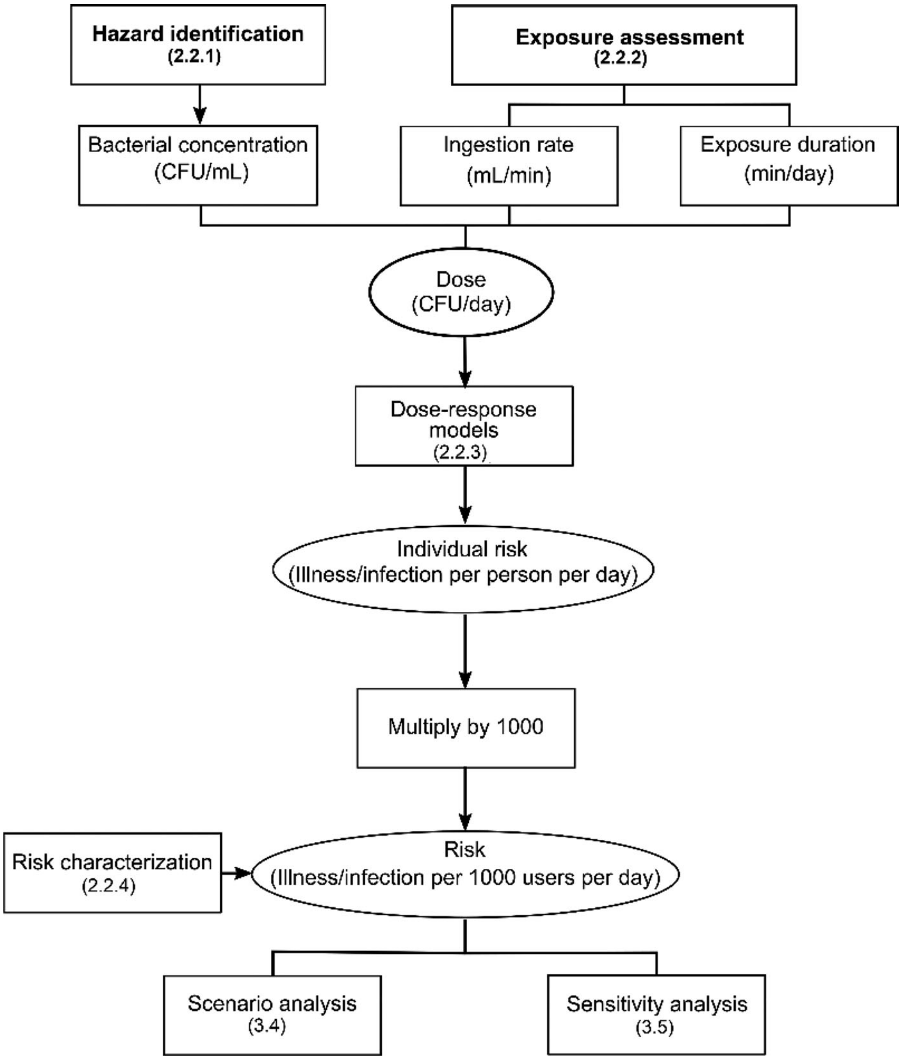

FIGURE 2 Flowchart of the calculation of illnesses/infections per 1000 users per day. In brackets are the number of the section detailing each step. *Source*: Sunger and Haas (2015).

performed). Water of 100 μL was used as it presented better results for platting compared to 1 mL. The agar plates were cultured and analyzed according to the protocol established by the company. For *Salmonella*, BPLS-Agar (modified) for isolation and identification of *Salmonella* except *Salmonella typhi* was used (Oxoid, Wesel, Germany), after 48 h at 36°C incubation pink colonies were counted. For *Vibrio* spp., TCBS-Agar plates were prepared according to the manufactures' protocol (Mibius, Düsseldorf, Germany), and after 24 h at 35°C incubation, colonies were counted. For *L. monocytogenes*, Brilliance Listeria agar plates were used (Oxoid, Wesel, Germany); after incubation for 48 h at 36°C, the plates were analyzed, and a number of colonies were counted. Regarding *Campylobacter* spp., we used *Campylobacter* selective agar (CCDA; blood free) (Oxoid, Wesel, Germany), and the plates were analyzed after 48 h incubation at 42°C in a microaerophile environment. The concentrations of bacteria analyzed using the platting method were calculated as CFU/100 mL.

Statistical analysis and probable health outcomes

The concentrations of *E. coli*, Enterococci, *Salmonella*, and *P. aeruginosa* were evaluated to identify the probability distribution that best represented the data obtained from each bacterium. The probability distributions, Weibull, γ, β, and Lognormal were tested using maximum likelihood estimation in RStudio (2020) software, and the goodness-of-fit parameters for all the distributions were determined using the Loglikelihood and Akaike criteria (AIC). The selected probability distribution was used later as input for the dose–response model (Section 2.2.3).

The QMRA was performed using as reference bacteria *E. coli*, Enterococci, and *Salmonella* to account for the probability of gastrointestinal illnesses and *P. aeruginosa* to assess the probability of infection due to dermal exposure. *Vibrio* spp., *L. monocytogenes*, and *Campylobacter* spp. were not included in the risk assessment study because their concentrations were always below the limit of detection (LOD) of the respective cultivation method.

2.2.2 | Exposure assessment

Field observations at the ornamental fountains

The Burano method was developed in 1972 by the social scientists Riege and Schubert (2002) who conducted observations in the Burano district regarding the presence of citizens at city square's at a given time and documented in a map (Riege & Schubert, 2002). For our study, an adaptation of the Burano method was used to monitor the behavior of the citizens engaging in recreational activities involving contact with water at the ornamental fountains. Video surveillance is a commonly used tool to gather data from field observations; however, we could not use this method due to data protection rules in Germany (Berding, 2020).

Between four and six visits of 60 min duration were made at each fountain in random days during the water sampling campaigns. The information collected during the visits was annotated in a spatial map of the fountain and surrounding area, including the type of water contact and respective exposure duration. The spatial map made for the Körtingbrunnen fountain is presented in Figure 3, as an example.

Regarding water contact, we defined three categories: (a) People having direct water contact are defined as those who had hand immersion in water, hand-to-mouth contact after touching water, water droplets falling in face or mouth, and drinking mouthfuls of water (Figure 3, red color); (b) people having indirect water contact are those who had contact with water through another person, animal, or object (Figure 3, yellow color); and (c) people having no water contact are defined as those who were in the surroundings of the fountain but did not have any observed interaction with water (Figure 3, green color).

For further analysis, the visitors were divided into two groups according to their estimated age: Visitors under an estimated age of 16 years were defined as children, whereas the others were treated as adults.

Dose quantification

In the following paragraphs, we describe the procedure used to estimate the ingestion rate (Q), the rate of water in contact with the skin of the hands (Q_H), and the time of exposure (t) required to determine the exposure dose.

For the ingestion exposure route associated with gastrointestinal illnesses, three main pathways were analyzed for people having direct water contact: ingestion due to hand-to-mouth contact, ingestion of water droplets during splashing, and ingestion of mouthfuls of water. The ingestion rates for each pathway and the total ingested rate of water were estimated using the following equations:

Ingestion rate per minute due to hand-to-mouth contact (Q_{HM})

$$\mathrm{Q}_{HM}\left(\text{¯L/min}\right) = h\,(\mathrm{mm})\,xA\left(\mathrm{mm}^2\right)xf_{HM}\left(n/\mathrm{min}\right). \quad (1)$$

Ingestion rate per minute due to water droplets (Q_D)

$$Q_D\left(\text{¯L/min}\right) = V_D\,(\text{¯L})\,xf_D\left(n/\mathrm{min}\right). \quad (2)$$

Ingestion rate per minute due to drinking mouthfuls of water (Q_M)

$$Q_M\left(\text{¯L/min}\right) = V_M\,(\text{¯L})\,xf_M\left(n/\mathrm{min}\right). \quad (3)$$

The total ingestion rate per minute was calculated as follows (Q):

$$Q\left(\text{¯L/min}\right) = Q_{HM}(\text{¯L/min}) + Q_D(\text{¯L/min}) + Q_M(\text{¯L/min}). \quad (4)$$

Values and probability distributions of the parameters V_D, f_D, h, A, and V_M were taken from the health risk assessment study for splash parks in the Netherlands done by Man, Bouwknegt et al. (2014), given the similarities with our study (Table 1). The values of the parameters f_{HM}, f_M, and f_H were obtained by pooling the data from our field observations of all the fountains and fitting it to a γ distribution, which is used to describe the waiting time between events (Table 1). The parameter Q_M was used as input only for the dose–response model of the Körtingbrunnen because drinking mouthfuls of water was observed only at this fountain.

For the dermal exposure route, the rate of water in contact with the skin of the hands (Q_H) was estimated using Equation (5) considering the parameters h, film thickness of water on hands, A_H, the surface area of the hands, and f_H, frequency of having hands immersed in water.

$$Q_H\left(\text{¯L/min}\right) = h\left(\mathrm{mm/min}\right)xA_H\left(\mathrm{mm}^2\right)xf_H\left(n/\mathrm{min}\right). \quad (5)$$

The parameters and statistical distributions used as input for the dose–response model are presented in Table 1.

The exposure duration (t) was determined through the field observations of recreational activities that involved direct contact with water. These data were then fitted to a β probability distribution in RStudio (2020). This distribution was chosen because it describes data falling within a specific interval, which in this case corresponds to the duration of the field observations.

2.2.3 | Dose–response models

The dose of exposure (d) to the several bacterial hazards (Equation 6) was calculated by multiplying the concentration of the bacteria in water (C), the rate of water ingested or in contact with the skin during exposure (Q) depending on the exposure route, and the time of exposure (t) of one recreational event (Haas et al., 2014):

$$d\left(\mathrm{MPN/event}\right) = C\left(\mathrm{MPN/mL}\right)xQ\left(\mathrm{mL/min}\right)xt\left(\mathrm{min/event}\right). \quad (6)$$

The bacterial concentrations were determined as described

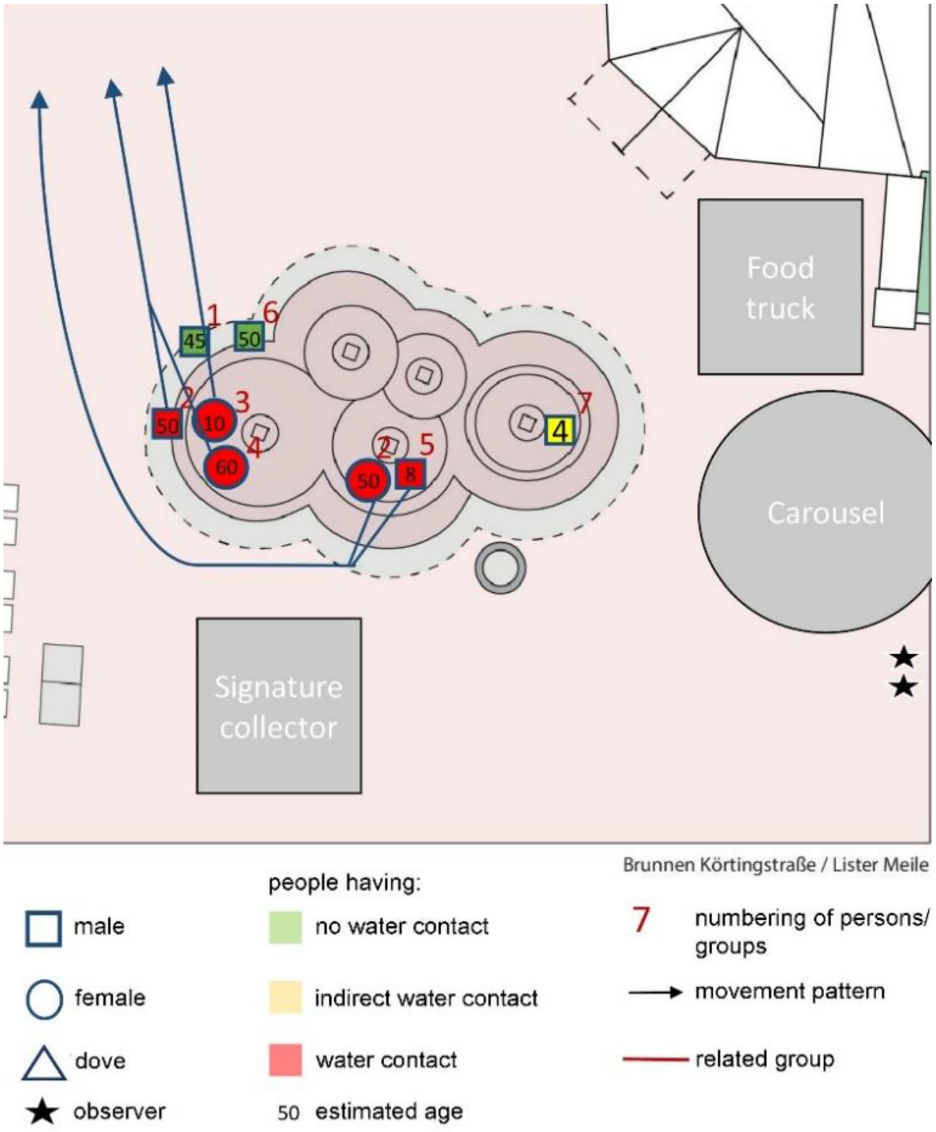

FIGURE 3 Example of field observation at the Körtingbrunnen.

TABLE 1 Exposure parameters used for ingestion and dermal exposure routes

Parameter	Distribution of values[a]	Source
A, surface area of the hand that is mouthed (mm^2)	U (100, 2000)	USEPA (2019)
A_H, surface area of the hand (mm^2)	U (15×10^3, 72×10^3)	USEPA (2019)
f_D, frequency of ingesting water droplets (n/min)	G (2.1, 0.17)	Man, Bouwknegt et al. (2014)
f_H, frequency of hand immersion	G (2.3, 0.65)	Field observations
f_{HM}, frequency of hand-to-mouth contact (n/min)	G (1.3, 0.8)	Field observations
f_M, frequency of taking a mouthful of water (n/min)	G (0.5, 1.4)	Field observations
h, film thickness of water on hands (mm)	U (1.97×10^{-2}, 2.34×10^{-2})	USEPA (2019)
V_D, volume of a water droplet (μL)	U (0.5, 524)	Man, Bouwknegt et al. (2014)
V_M, volume of a mouthful of water (μL)	G (4.72, 5.3×10^3)	USEPA (2019)

[a] U, uniform probability distribution (min, max); G, γ probability distribution (shape, scale). All the values in the table are for children.

TABLE 2 Dose response models used for the selected bacteria

Bacteria	Dose response model	Parameters	Source
Escherichia coli (ETEC O111)	$P_{ill} = 1 - [1 + d \times ((2^{(1/\alpha)} - 1)/N_{50})]^{-\alpha}$	$\alpha = 2.63 \times 10^{-1}$ $N_{50} = 3.56 \times 10^{6}$	CAMRA (2020b)
Enterococci	$P_{ill} = 1 - [1 + d \times ((2^{(1/\alpha)} - 1)/N_{50})]^{-\alpha}$	$\alpha = 1.6 \times 10^{-1}$ $N_{50} = 59.9 \times 10^{3}$	Sunger and Haas (2015)
Salmonella	$P_{ill} = 1 - [1 + d \times ((2^{(1/\alpha)} - 1)/N_{50})]^{-\alpha}$	$\alpha = 31.26 \times 10^{-2}$ $N_{50} = 23.6 \times 10^{3}$	WHO (2001)
Pseudomonas aeruginosa	$P_{inf} = 1 - \exp^{-k \times d}$	$k = 4.3 \times 10^{-7}$	Roser et al. (2015)

in Section 2.2.1. The exposure rates were calculated using Equations (4) and (5), and the time of exposure was quantified during the field observations. The risk of GI illness per 1000 users per day (P_{ill}) due to ingestion of *E. coli*, Enterococci, and *Salmonella* was estimated according to the β-Poisson dose–response model (Equation 7).

The analytical methods used in our study to quantify *E. coli* and Enterococci are not designed specifically to identify pathogenic strains. Therefore, we assumed a "worst case scenario" in which all *E. coli* and Enterococci present in our samples were pathogenic for the calculation of the risk of illness (P_{ill}). We considered pathogenic *E. coli* strain ETEC O111 (CAMRA, 2020b) and pathogenic Enterococci (Haas et al., 2014). We made this assumption because there are no regulations mandating water quality monitoring in ornamental fountains, and in most cases, the water is continuously recirculated without any treatment during the summer. As a result, our risk estimate may be overestimated due to the conservative assumptions made in our calculations:

$$P_{ill} = 1 - [1 + dx((2^{(1/^{\alpha})} - 1)/N_{50})]^{-\alpha}. \tag{7}$$

The values for the parameters α and N_{50} were taken from the literature, as presented in Table 2.

Additionally, the risk of dermal infection per 1000 users per day (P_{inf}) due to exposure to *P. aeruginosa* was estimated with the exponential dose–response model (Equation 8) (Roser et al., 2015):

$$P_{inf} = 1 - \exp^{-k \times d}. \tag{8}$$

2.2.4 | Risk characterization

To account for uncertainty in the exposure parameters and time of exposure (t), Monte Carlo simulations were performed in MATLAB (2020); the software generated 10.000 combinations of the parameters of the dose–response model to estimate the final risk of illness/infection. For this study, all the model parameters were assumed to be independent.

Moreover, a scenario analysis was carried out with different concentrations in the range from 1×10^{1} to 1×10^{4} MPN/100 mL. Afterward, a sensitivity analysis was done to quantify the contribution of each parameter in percentage to the final risk of illness/infection. This analysis was executed using the Microsoft Excel Add-In Oracle Crystal Ball (), which computes the contribution to the variance of each parameter by squaring the rank correlation coefficients and normalizing them to 100%.

2.2.5 | USEPA mean illness rate

The USEPA carried out the National Epidemiological and Environmental Assessment of Recreational Water study (NEEAR study) published in 2003, in which a broader definition of gastrointestinal illness than the one considered in the guidelines of 1986 was used. NEEAR-gastrointestinal illnesses (NGI) definition includes diarrhea, stomachache, or nausea without the requirement of fever. This was included in the USEPA guidelines for recreational water quality criteria (RWQC) of 2012, which established an estimated illness rate of 32 NGI/1000 or 36 NGI/1000, depending on the targeted water quality.

Thus, the calculated illness and infection estimates were compared with an estimated illness rate of 36 NGI/1000 users (USEPA, 2012). There is no estimated illness or infection rate for dermal infections established in the USEPA (2012); however, the NEEAR study also found that other waterborne illnesses occur at lower rates than GI illnesses. Therefore, protecting public health against GI illnesses will also prevent most types of illnesses related to recreational activities in water, which is why we used the same benchmark to compare the risk of skin infections (USEPA, 2012).

The risk estimate for GI illness per 1000 users was calculated in the present study as follows; first, the dose was calculated by running Monte Carlo simulations from the bacterial concentration distribution, ingestion rate distribution, and exposure duration distribution identified for each fountain in previous steps, the obtained values were then replaced in the appropriate dose–response model to obtain the individual probability of a person getting ill/infected; finally, these individual risk estimates were then multiplied by 1000 to estimate the risk of illness/infection per 1000 users.

3 | RESULTS AND DISCUSSION

3.1 | Hazard identification

Several bacterial hazards may be present in urban waters, depending on the water system being analyzed and the source of the water (Ortells Sales, 2015). To determine the water quality of the fountains, we analyzed *E. coli*, Enterococci, *Salmonella*, *Vibrio* spp., *L. monocytogenes*, *Campylobacter* spp., and *P. aeruginosa*.

Campylobacter spp. can not only have human or animal fecal origin and are commonly found in rivers, groundwater, and sewage but have also been found in drinking water (Jones, 2001). Katukiza et al. (2014) and Dale et al. (2010) found *Salmonella* in drinking water systems during their studies. Furthermore, *Campylobacter* spp. together with *Salmonella* spp. are the most important causes of gastrointestinal infections in Europe (ECDC, 2014).

Brehm et al. (2021) found that severe heatwaves may be responsible for infections associated with *Vibrio* spp. in Germany, as the number of human infections linked to this bacterium increased significantly during the summer months of 2018 and 2019. *L. monocytogenes* is mostly a foodborne pathogen causing infections mainly in immunocompromised individuals; however, aquatic environments can be a potential source of transmission to animals and the food chain. Raschle et al. (2021) reported the occurrence of *L. monocytogenes* in surface waters in Switzerland, highlighting the potential of rivers and inland channels as reservoirs for this bacterium; it is ubiquitous in the environment and can form biofilms.

However, concentrations of *Vibrio* spp., *L. monocytogenes*, and *Campylobacter* spp. were always below the LOD.

Legionella pneumophila is a waterborne pathogen found in natural water as well as in man-made water systems and is the causative agent of Legionellosis, a severe pneumonia caused by inhalation of aerosols contaminated with this bacterium. An outbreak of Legionellosis originating from a decorative water fountain has been reported in a previous study (Smith et al., 2015). However, this bacterium was not analyzed because the inhalation exposure route was not considered in our study.

In our study, bacterial concentrations were highly variable at each location during the monitoring (Table 3).

The highest concentrations of the selected bacteria were observed at the Körtingbrunnen and the lowest at the Blätterbrunnen, except for *P. aeruginosa*, where the lowest concentrations were found at Klaus–Bahlsen–Brunnen.

The USEPA recommends in the RWQC 2012 that the geometric mean of a water body should not exceed 12.6 × 10^1 CFU/100 mL for *E. coli* and 3.5 × 10^1 CFU/100 mL for Enterococci in any 30-day interval; these concentrations correspond to an estimated illness rate of 36 NGI per 1000 primary contact recreators. Based on these criteria, the Blätterbrunnen was the only fountain for which *E. coli* and Enterococci concentrations were below these thresholds (Table 3). This could be explained by the retention basin that the Blätterbrunnen has, which can work as a barrier for dogs, mice, and other animals as well as protection from surface runoff. Conversely, the rest of the fountains are open and offer free access for vectors and surface runoff that might bring microbial pollution to the water.

At the Körtingbrunnen and Marstallbrunnen, dogs and several birds were also seen during field observations (cats and rodents cannot be excluded during the night). Both fountains have similar construction, and even though the Marstallbrunnen has an automatic chlorine disinfection system, high fecal contamination regarding *E. coli* was observed in both fountains (Table 3). Our results are consistent with those found by Man, Heederik et al. (2014) where 30% of the studied water features fed with tap water exceeded the standards for fecal indicators in recreational waters according to the USEPA (2012).

E. coli and Enterococci have been used as microbial indicators of fecal pollution both in marine and freshwater systems (Jang & Liang, 2018); nonetheless, a study carried out in German drinking water networks showed that most of the Enterococci species found in drinking water systems were not assigned to the intestinal strains, suggesting that it could be introduced to the water by invertebrates (Technologiezentrum Wasser, 2019). As mentioned before, three of the four studied fountains have open access, allowing not only people to have contact with the water but also domestic animals, birds, and other vectors, which can bring fecal pollution to the water; thus, to confirm the origin of this bacterial pollution, microbial source tracking, which allows discrimination between human and nonhuman fecal sources, should be performed in the future.

In our study, concentrations of *Salmonella* were much higher than those found by Goh et al. (2015) at the Marina reservoir, which is used as freshwater recreational site and potable water source. Moreover, Ahmed et al. (2010) found a concentration range of *Salmonella* spp. of 6.5 × 10^1 to 3.8 × 10^2 per 1000 mL in roof-harvested rainwater; in our study, this range was exceeded in three of the four water fountains, except at the Blätterbrunnen (Table 3), this could be explained by the bacterial pollution brought through birds (observed during field observations), as well as the bacterial load collected when water washes down the surrounding surface of the fountains and is continuously recirculated.

For *P. aeruginosa*, critical concentration and outbreak data related to this bacterium in recreational sites are lacking in the literature (Rasheduzzaman et al., 2019; Roser et al., 2015). From the review made by Roser et al. (2015), 1 × 10^6 CFU/100 mL is considered the minimum concentration to constitute a hazard for skin infections, which is much higher than the concentration we found in the studied water fountains (Table 3). Moreover, the concentrations obtained in our study were consistent with the results reported in the study by Akturk et al. (2012), who also found *P. aeruginosa* in different sections of a drinking water pipeline, confirming that the presence of this bacterium in drinking water can

TABLE 3 Geometric mean and 95th-percentile of bacteria concentration in water from the ornamental fountains

Fountain	Parameters	*Escherichia coli* (MPN/100 mL)	Enterococci (MPN/100 mL)	*Salmonella* (CFU/100 mL)	*Pseudomonas aeruginosa* (MPN/100 mL)
Blätterbrunnen	*n*	13	12	13	13
	GM	2.6×10^0	2.6×10^0	4.0×10^2	2.9×10^2
	95%	7.3×10^1	4.9×10^1	4.2×10^4	1.5×10^4
Klaus–Bahlsen–Brunnen	*n*	9	9	11	8
	GM	2.2×10^2	4.1×10^2	1.2×10^4	7.3×10^2
	95%	1.8×10^3	2.2×10^3	1.2×10^5	6.9×10^3
Körtingbrunnen	*n*	9	9	10	9
	GM	1.9×10^2	2.7×10^2	5.6×10^4	5.1×10^2
	95%	1.8×10^3	3.8×10^3	1.3×10^6	1.5×10^5
Marstallbrunnen	*n*	9	9	10	9
	GM	1.4×10^2	1.2×10^2	7.3×10^3	2.4×10^2
	95%	7.8×10^2	1.5×10^3	9.5×10^4	2.5×10^4

Abbreviations: CFU, colony forming units; GM, geometric mean; MPN, most probable number.

have its origin in biofilm formed in pipelines. Furthermore, the lack of regular inspection and maintenance of the fountains could also explain and affect the presence of bacterial pathogens in the water.

3.2 | Exposure assessment

3.2.1 | Field observations

Field observations were held during clear-sky days with temperatures that ranged between 20 and 32°C, as these water features are visited by many people during warm days. A total of 499 people were observed between the four ornamental fountains from which 30% were children assumed to be below 16-year old. Moreover, 70% of the people were observed among the Körtingbrunnen and Marstallbrunnen, both found in busy areas with many restaurants, cafes, and shops. Most of the children at these two fountains were seen having direct water contact.

At the Blätterbrunnen, the people observed were mainly sitting around the fountain; most of them had no water contact. On the other hand, at the Klaus–Bahlsen–Brunnen nearly all the children observed had direct water contact (Figure 4a).

People observed having direct water contact at the fountains were 151 in total, of which 70% were children and 30% adults. From these data, it can be inferred that children are the population under higher risk at the selected fountains (see Figure 4a); hence, the risk of illness/infection due to ingestion and dermal exposure was calculated only for children.

The proportion of children observed during our study was 30% of a total of 499 people; moreover, we identified having wet feet, washing hands and face, and, seldomly, head immersions and drinking mouthfuls of water by children during a recreational event. Similarly, Man, Bouwknegt et al. (2014) observed a total of 604 individuals at splash parks in the Netherlands, of which 42.5% were children. They also identified the main exposure pathways as having wet hands, wet faces, drinking mouthfuls of water, and being present within 2 m of water spray. This indicates that the main

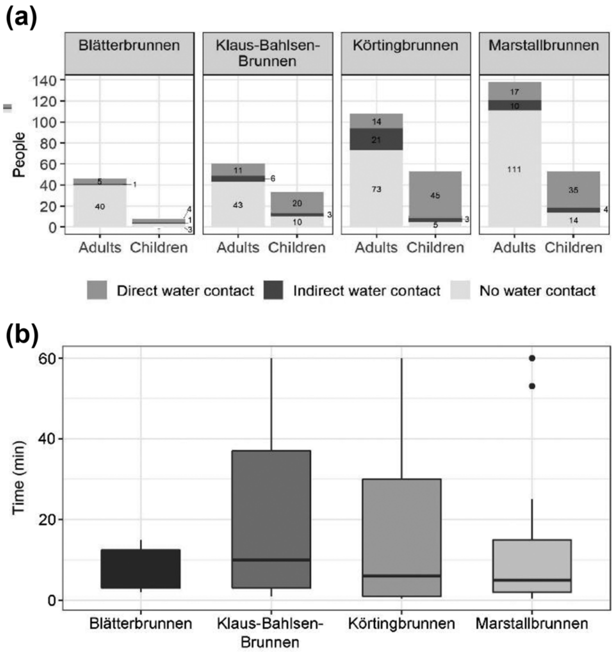

FIGURE 4 (a) Number of people observed per place and type of exposure. People having direct water contact are defined as those who had hand immersion in water, hand-to-mouth contact after water contact, water droplets falling in face or mouth, and drinking mouthfuls of water. Indirect water contact refers those who had contact with water through another person, animal, or object, and no water contact refers as those who were in the surroundings of the fountain but did not have any observed interaction with water; (b) boxplot for the time of exposure of people who had direct water contact at each fountain. Line inside the box represents the median value, box represents the interquartile range (25–75 percentiles), black dots outside box represent the outliers, and whiskers show the maximum and minimum values.

TABLE 4 Parameters describing the β probability distribution of the time of exposure at each fountain

Fountain	Parameters of the probability distribution	
Blätterbrunnen	$\alpha = 0.35$	$\beta = 0.66$
Klaus–Bahlsen–Brunnen	$\alpha = 0.34$	$\beta = 0.70$
Körtingbrunnen	$\alpha = 0.30$	$\beta = 0.69$
Marstallbrunnen	$\alpha = 0.32$	$\beta = 1.22$

exposure routes to microbial hazards observed for children in both studies are ingestion and skin contact with water.

The total time of exposure (t) of people who had direct water contact varied depending on the fountain (Figure 4b). However, the mean time of exposure at each fountain was not significantly different (p-value >0.05).

The data collected from field observations were used to fit a β distribution, which was afterward used as input for the Monte Carlo simulation, the corresponding parameters can be found in Table 4.

3.2.2 | Dose quantification

When performing a QMRA, it is important to consider the microorganisms' distribution in the water. Bacteria are discrete variables whose concentration can vary with each event; therefore, bacterial statistics should be characterized to acknowledge the risk differences from diverse concentration exposures (Haas et al., 2014).

Concentration of *E. coli* in three of the fountains was described by a γ probability distribution; however, in the case of the Blätterbrunnen, the concentration followed a log-normal probability distribution. Regarding Enterococci, concentrations at Blätterbrunnen, Klaus–Bahlsen–Brunnen, and Marstallbrunnen fitted a Weibull distribution, whereas for the Körtingbrunnen, a γ distribution was the best fit (Table 5).

Salmonella concentrations fitted a γ distribution for all the fountains. Furthermore, the probability distribution for *P. aeruginosa* concentrations at the Blätterbrunnen and the Klaus–Bahlsen–Brunnen followed a γ distribution, whereas for the Körtingbrunnen and Marstallbrunnen a Weibull distribution showed the best fit (Table 5).

For the present study, hand-to-mouth contact, water droplets falling in the mouth, and drinking mouthfuls of water have been combined in the ingestion pathway.

3.3 | Risk assessment

Exposure to the selected bacteria is given by the dose, namely, the number of bacteria ingested or in contact with the individuals per day. Afterward, the risk of illness/infection is calculated by applying the dose–response relation corresponding to each bacterium.

A point estimate calculation of the risk of illness/infection is a widely used approach in QMRA; however, we applied a probabilistic approach because it considers the variability and uncertainty within each input parameter. Thus, as input for the dose–response model, the probability distributions of bacterial concentration, exposure rates, and time of exposure were used.

To analyze the risk of GI illness due to ingestion of *E. coli*, Enterococci, *Salmonella*, as well as dermal infection due to *P. aeruginosa*, Monte Carlo simulations were run considering the respective dose–response model of each bacterium, and the results are displayed in box-and-whisker plots (Figure 5).

Considering that recreational activities do not take place every day of the year, the risk of illness and infection is measured in units per day, eliminating the dependency on the days and assuming that a person is exposed to one recreational event per day (Haas et al., 2014). For the risk assessment in this study, it was assumed that no bacterial decay happened during water transport and exposure.

The results show that the risk of gastrointestinal illness due to *E. coli* is below the USEPA mean illness rate for all the fountains investigated (Figure 5a). In contrast, the risk of gastrointestinal illness due to Enterococci (Figure 5b) is above the USEPA benchmark at the Körtingbrunnen, Klaus–Bahlsen–Brunnen, and Marstallbrunnen fountains. At the Blätterbrunnen, the simulated values above the 75th percentile also exceed the USEPA mean illness rate. The difference in illness risk results between these two bacteria may be due to a lower infective dose for Enterococci used in the dose–response model. In addition, the three fountains that exceeded the USEPA benchmark also had longer exposure times compared to the Blätterbrunnen. These factors likely contributed to the higher risk of enterococcal illness at these three fountains.

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Soller et al. (2014) assessed human health risks derived from exposure to multiple sources of fecal indicator bacteria and concluded that recreational waters affected by *E. coli* and Enterococci from nonhuman sources have reduced risks to human health compared to waters impaired by human sewage sources. However, it should be kept in mind that our study considers a "worst case scenario" and assumes that all *E. coli* and Enterococci found in the samples are pathogenic, as previously explained.

The risk of GI illness due to *Salmonella* (Figure 5c) and the risk of infection due to *P. aeruginosa* (Figure 5d) are below the benchmark for three of the four fountains; however, both risks exceeded the benchmark at the Körtingbrunnen. This could be explained by higher exposure times and volumes at this fountain, due to observed ingestion of mouthfuls of water and higher bacterial concentrations found during lab analysis.

Goh et al. (2015) also performed a QMRA for *Salmonella* spp. and *Enterococcus* in a freshwater reservoir in Singapore used for recreational purposes and concluded that the illness risk derived from *Salmonella* was under the acceptable

TABLE 5 Best fit probability distributions and parameters used for bacterial concentration

Fountain	Parameters	*Escherichia coli*	Enterococci	*Salmonella*	*Pseudomonas aeruginosa*
Blätterbrunnen	data points	13	12	13	13
	Prob dist.	Log-norm	Weibull	γ	γ
	Parameters	$\mu = -3.65$	$k = 0.55$	$\alpha = 0.23$	$\alpha = 0.28$
		$\sigma = 1.75$	$\lambda = 0.06$	$\beta = 0.002$	$\beta = 0.008$
Klaus–Bahlsen–Brunnen	Data points	9	9	11	8
	Prob dist.	γ	Weibull	γ	γ
	Parameters	$\alpha = 0.62$	$k = 0.84$	$\alpha = 0.50$	$\alpha = 0.50$
		$\beta = 0.10$	$\lambda = 8.15$	$\beta = 0.02$	$\beta = 0.02$
Körtingbrunnen	Data points	9	9	10	9
	Prob dist.	γ	γ	γ	Weibull
	Parameters	$\alpha = 0.53$	$\alpha = 0.56$	$\alpha = 0.53$	$k = 0.28$
		$\beta = 0.08$	$\beta = 7.71$	$\beta = 0.08$	$\lambda = 44.58$
Marstallbrunnen	Data points	9	9	10	9
	Prob dist.	γ	Weibull	γ	Weibull
	Parameters	$\alpha = 0.68$	$k = 0.63$	$\alpha = 0.54$	$k = 0.34$
		$\beta = 0.21$	$\lambda = 3.03$	$\beta = 0.002$	$\lambda = 13.12$

benchmark, which coincides with the results of three of the ornamental fountains in the present study; however, high concentrations of these bacteria and a high ingestion rate might be of concern for the public health at the Körtingbrunnen.

Bollaerts et al. (2008) modeled dose–illness relationships with data from *Salmonella* outbreaks considering normal and susceptible subpopulations; they concluded that the normal population showed immunity to these bacteria. However, susceptible population, such as newborns, young children, pregnant women, elderly, and immunocompromised persons, showed a higher probability of getting ill at low dose levels. This should be borne in mind as the present study did not consider differences in host susceptibility (Bollaerts et al., 2008).

A similar trend was observed for *P. aeruginosa* showing the highest risk of infection due to dermal exposure at the Körtingbrunnen, which could be explained by higher concentrations of this bacterium compared to the other fountains, as well as longer times of exposure. Our results are comparable to those of Roser et al. (2015), who reported that concentrations of 10^4 CFU/mL of *P. aeruginosa* could cause an outbreak to a very low extent, and a minimum geometric mean of 1.8×10^7 CFU/mL is needed for all the exposed population to get folliculitis. Concentrations of *P. aeruginosa* found during our monitoring varied between 1×10^{-3} and 2.4×10^3 MPN/mL, which could represent a risk of infection for susceptible population at the Körtingbrunnen (Figure 5d). Moreover, Vukić Lušić et al. (2021) suggested that due to the widespread prevalence of this bacterium, it may not pose a significant threat to the general public.

Our study identified several exposure pathways for children during recreational events, including wet feet, wet hands, water droplets falling in the face and mouth, and occasional drinking mouthfuls of water and immersing the head. Among these pathways, hand-to-mouth contact after getting wet hands and water droplets falling into the mouth were the most frequently observed routes for children. These two pathways, along together with drinking mouthfuls of water due to high volumes, pose the greatest risk of exposure to children. Byrne et al. (2021) and Verbyla et al. (2019) also identified these pathway routes as the main exposure concern, highlighting the urgency of implementing water quality monitoring at water fountains.

3.4 | Scenario analysis for different bacterial concentrations

The scenario analysis aimed to show how different bacterial concentrations influence the final risk of illness/infection during a recreational event. A scenario analysis was performed with different concentrations ranging between 1×10^1 and 1×10^4 MPN/100 mL, including the criteria established by the USEPA for *E. coli* of 12.6×10^1 CFU/100 mL, and Enterococci, 3.5×10^1 CFU/100 mL (USEPA, 2012).

In the scenario analysis, we compared exposures at the Körtingbrunnen and at the Blätterbrunnen to evaluate the effects of different exposure times and volumes in the health risk, as at the Körtingbrunnen the exposure times and volumes were the highest among the fountains. For this analysis, we considered the risk of GI illness and dermal infection as a function of the time of exposure (Figure 6).

Figure 6 "*E. coli*" suggests that concentrations of *E. coli* at the Körtingbrunnen could be as high as the USEPA recommendation value of 12.6×10^1 CFU/100 mL for exposures up to 1 h without exceeding the benchmark. However,

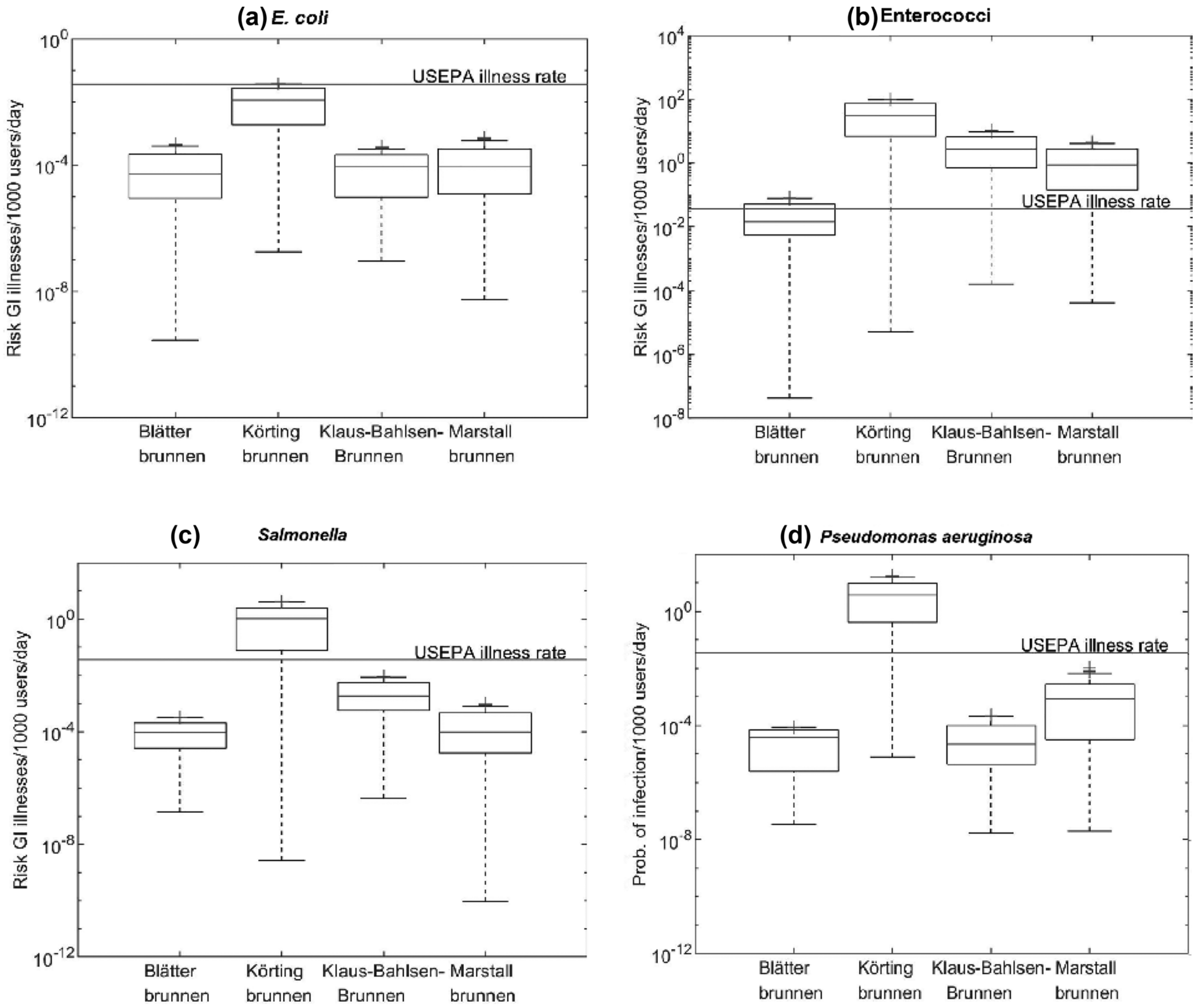


FIGURE 5 Risk of illness/infection per 1000 users per day at each ornamental water fountain due to exposure to (a) *Escherichia coli*, (b) Enterococci, (c) *Salmonella*, and (d) *Pseudomonas aeruginosa* obtained from the Monte Carlo simulations. Horizontal line represents USEPA mean illness rate of 36/1000 users. Line inside the boxes represents the median value, box represents the interquartile range (25–75 percentiles), crosses outside box represent the outliers, and whiskers show the maximum and minimum values.

exposures above 10 min of duration to concentrations higher than 1 × 10^3 CFU/100 mL could entail a risk of illness above the 36/1000 benchmark at this fountain. For the Blätterbrunnen, 1 × 10^4 CFU/100 mL during 60 min of exposure would not exceed the benchmark. This could be explained by a different distribution of the time of exposure and higher ingestion rates at the Körtingbrunnen.

Figure 6 "Enterococci" shows that concentrations of Enterococci at the Körtingbrunnen can be 1 × 10^1 CFU/100 mL for exposures up to 10 min without exceeding the mean illness benchmark; higher concentrations could involve adverse health outcomes to the exposed population. Conversely, at the Blätterbrunnen fountain, a concentration of up to 1 × 10^2 CFU/100 mL for exposure periods up to 60 min would not exceed the benchmark. These results are consistent with the values suggested by Wiedenmann et al. (2006) as reasonable estimates for no-observed-adverse-effect levels, which are 100 CFU/100 mL and 25 CFU/100 mL for *E. coli* and Enterococci, respectively. Nevertheless, they considered bathing exposures during a 10 min period with at least three head immersions in fresh recreational waters, which represent greater exposure volumes than those considered in our study as well as a different water source.

The data presented in Figure 6 regarding *Salmonella* indicate that exposures up to 10 min at the Körtingbrunnen with a concentration of 1 × 10^1 CFU/100 mL would not exceed the benchmark. However, to minimize the risk of illness, lower concentrations should be maintained for longer exposure periods. On the other hand, at the Blätterbrunnen, concentrations of up to 1 × 10^2 CFU/100 mL for 60 min would not exceed the USEPA mean illness rate. It is worth noting that the discrepancy between the two sites may be due to differences in the amount of water ingested and the distribution of exposure time.

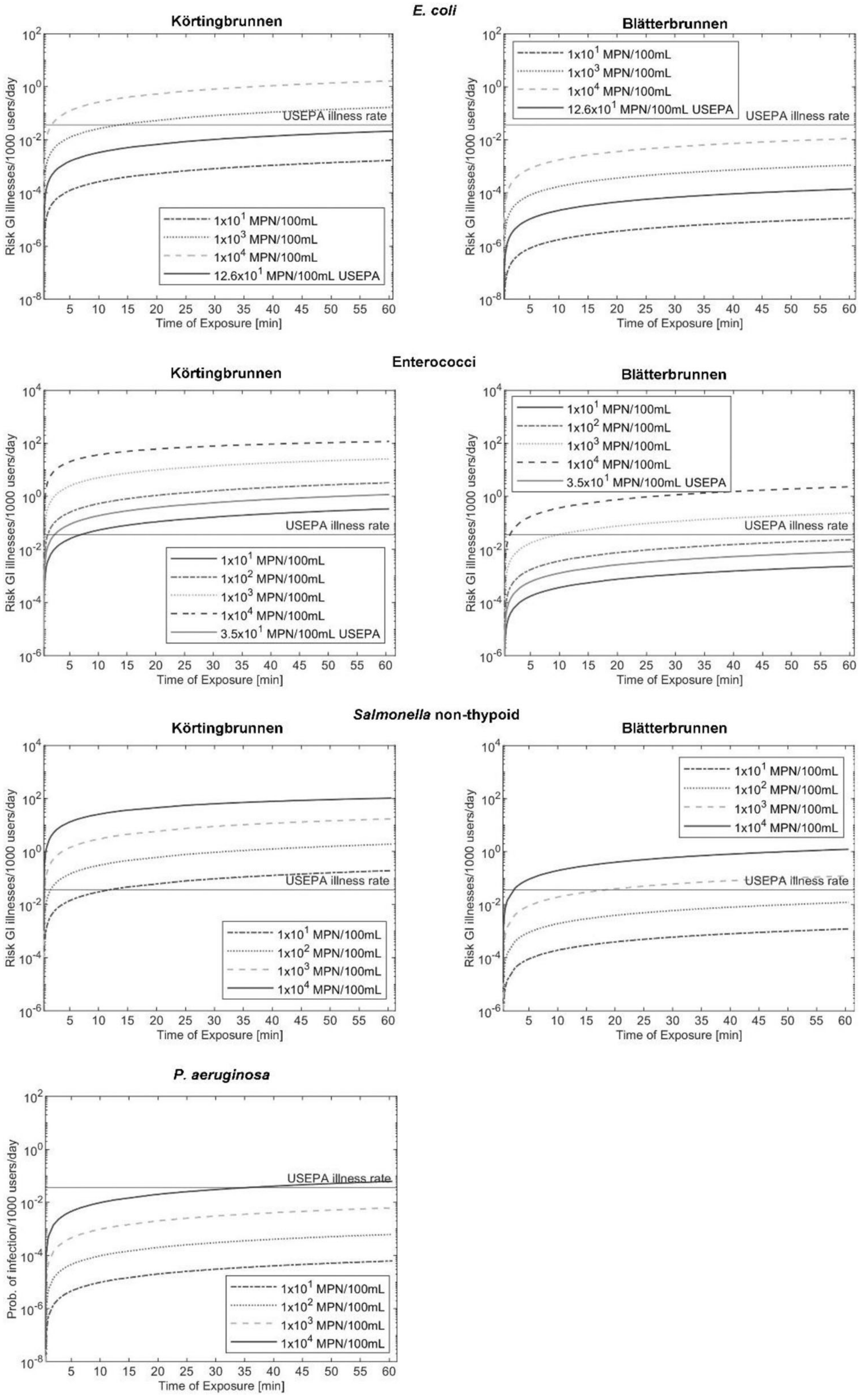


FIGURE 6 Scenario analysis for *Escherichia coli*, Enterococci, *Salmonella*, and *Pseudomonas aeruginosa* at Körtingbrunnen and Blätterbrunnen fountains.

McBride et al. (2013) performed a QMRA from exposure to stormwater pathogens in recreational waters and despite having different water sources, the concentrations obtained for *Salmonella* are similar to our study. We found that concentrations above 1×10^3 CFU/100 mL after 15 min exposure could represent the high risk of infection, whereas they suggest that the incidence of the probability of illness due to exposure to this bacterium was low in their studied locations.

Figure 6 for "*P. aeruginosa*" only shows results at the Körtingbrunnen as it had a longer exposure time. For the dermal exposure route, the parameters were identical for all of the studied fountains. This scenario analysis shows that even high concentrations of 1×10^4 MPN/100 mL within a period of 30 min exposure would not exceed the USEPA benchmark. This statement is consistent with prior research indicating that this bacterium present in aquatic environments does not pose a significant threat to the general public (Hardalo & Edberg, 1997; Vukić Lušić et al., 2021).

3.5 | Sensitivity analysis

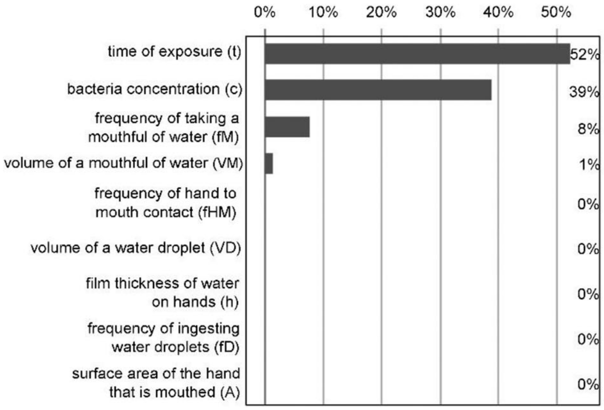
To estimate the human health risks related to recreational exposure, QMRA employs several parameters as input for the dose–response model, which are subject to uncertainty. Thus, a sensitivity analysis was performed to investigate how the final risk of illness/infection is influenced when the parameters vary within their uncertainty range and which parameters have the greatest effect on the variance of the final risk outcome (Eregno et al., 2016).

The assessed parameters were the film thickness of water on hands (h), the surface area of the hand that is mouthed (A), the frequency of hand-to-mouth contact (f_{HM}), the volume of a water droplet (V_D), the frequency of ingesting water droplets (f_D), the volume of a mouthful of water (V_M), the frequency of taking a mouthful of water (f_M), the time of exposure (t), and bacterial concentration (C). The parameters α, β, N_{50}, and k of each dose–response model are point estimates obtained from the literature, and they were not considered in the sensitivity analysis as they may vary from individual to individual (Perez-Rodriguez, 2021).

For the sensitivity analysis (Figure 7), only the dose–response for Enterococci at the Körtingbrunnen and Klaus–Bahlsen–Brunnen was considered as these were the bacterium and fountains, which showed the highest risk of GI illness.

From the sensitivity analysis (Figure 7), the parameter that has the greatest contribution is the time of exposure (t), followed by the bacterial concentration (C). On the other hand, the parameters with the lowest contribution were the surface area of the hand that was mouthed (A) and the film thickness of water on hands (h). The studies performed by Wolfgang (2012) and Eregno et al. (2016) also reported that pathogen concentration defines the final exposure dose and, thus, dominates the final risk outcome.

(a) Contribution to variance: Körtingbrunnen



(b) Contribution to variance: Klaus-Bahlsen-Brunnen

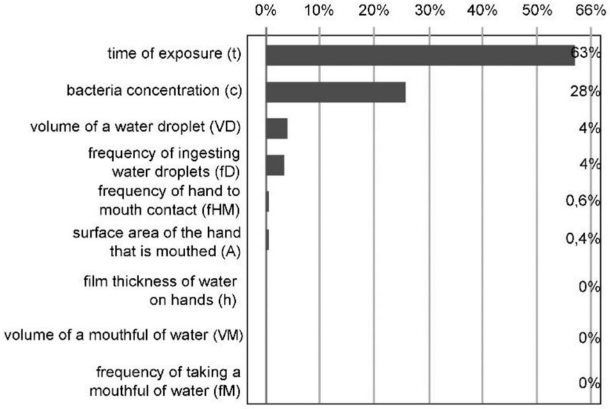


FIGURE 7 Sensitivity analysis expressed as contributions to variance of the final risk of infection due to Enterococci at (a) Körtingbrunnen and (b) Klaus–Bahlsen–Brunnen.

4 | CONCLUSION

This study is the first QMRA performed for ornamental fountains fed with drinking water in Hannover city. Although ornamental fountains are an excellent option to deal with the negative effects of global warming by providing refreshing environments within cities, the results of our study confirm the presence of potentially pathogenic bacteria in ornamental water fountains used for recreational purposes and fed with drinking water.

Although the health outcome for most of the studied fountains did not exceed the USEPA mean illness rate, this dramatically changes when the microbiological water quality deteriorated. Further microbial source tracking is needed to clarify the source of pollution. Preventative measures, such as water quality monitoring and warning signs discouraging people from drinking the water of ornamental fountains, can help reduce exposure volumes and thus adverse health effects to the exposed population.

The high concentrations of *P. aeruginosa* found in the fountains suggest the occurrence of water stagnation either in the fountain's structures or in the water supply network; a more detailed assessment of the operation and maintenance of these ornamental fountains are required to confirm this and subsequently implement appropriate technical measures.

There are currently no water quality criteria established for water features in public places in Germany. Our study emphasizes the importance of such guidelines being put in place to minimize health risks associated with exposure to ornamental fountains. The scenario analysis presented here can help with the development of water quality standards to be applied to these water features to protect public health. Thus, the scientific results presented in this article can be of benefit to policy makers when launching new water quality standards and for implementation and operation guidelines of new urban recreational areas.

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