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RESEARCH ARTICLE

Exposure parameters and health risk of *Cryptosporidium* and *Giardia* in the recreational water activities for urban residents in China

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Abstract

Knowledge gaps in the exposure parameters for recreational water activities make quantitative risk assessment related to water recreation difficult. Therefore, the annual exposure frequency and single exposure duration for the recreational water activities of residents from ten cities in the North and South of China were investigated. Questionnaire interviews were carried on recreational water activities comprising swimming (SW), boating (BA), playing in interactive fountains (PF), and watching fountains (WF). Quantitative microbial risk assessment for the exposure of urban residents to *Cryptosporidium* and *Giardia* was also performed. For the four recreational water activities, the participation rates of urban residents in SW and WF were higher than the others. For SW and BA, the mean annual exposure frequency and single exposure duration for males were significantly higher than those for females. PF and WF showed the opposite. The annual exposure frequency for above 35-year-old residents was higher than that for young residents (18–35 years). However, the single exposure duration for young residents was highest in SW, BA, and PF. The mean annual exposure frequency and single exposure duration for North China residents were higher than those for South China residents in all recreational water activities, except for SW. Overall, the annual exposure frequency and single exposure duration in recreational water activities for all urban residents followed a lognormal distribution. In the four recreational water activities, the total annual infection risk of male exposure to *Cryptosporidium* was 1.0×10^{-2}, with the confidence intervals between 95 and 5% of [4.3×10^{-4}, 3.7×10^{-2}], whereas that for females was 6.8×10^{-3} and [4.2×10^{-4}, 2.4×10^{-2}]. Also, the annual infection risk of males to *Giardia* was 8.8×10^{-3} and [5.1×10^{-4}, 3.2×10^{-2}], and that of females was 5.3×10^{-3} and [4.0×10^{-4}, 1.8×10^{-2}]. These results demonstrated that SW and PF made the highest contribution to the total annual infection risk. Sensitivity analysis highlighted that the characterization of exposure parameters plays a critical role in health risk assessment, which may provide a scientific basis for recreational water quality standards formulation.

Keywords Recreational water activities · Exposure parameters · Quantitative microbial risk assessment · Infection risk · *Cryptosporidium* and *Giardia*

Highlights The participation rates in SW and WF were higher
The exposure parameters were followed to lognormal distribution
The annual infection risk was exceeded 0.0001 pppy in SW, BA and PF
SW and PF made the greatest contribution to the total annual infection risk

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Introduction

Landscape water and recreational water play important roles in the development of cities and the urban water environment. As the construction of landscape water and recreational water increase, too does residents' participation in hydrophilic activities. However, unlike the traditional recreational water activity of swimming, nowadays, recreational water activities have become more diverse to encompass boating (Xiao et al. 2018), playing in interactive fountains, and watching fountains (De Man et al. 2014b). These recreational water activities form new types of hydrophilic activities. These hydrophilic activities, whereby people come into direct contact with a water body, are also sometimes referred to as landscape water. Thus, there is no clear distinction between landscape water and recreational water in China. These landscape water bodies are usually open storage and susceptible to pollution from various natural, human, and non-human sources (Soller et al. 2010a; Soller et al. 2010b). As such, they may contain a variety of pathogenic microorganisms and toxic substances, including *Salmonella* (Zhang et al. 2019), enteroviruses (Lodder et al. 2015), human adenoviruses (Vergara et al. 2016), noroviruses (Vergara et al. 2016), *Cryptosporidium* (Suppes et al. 2016; Xiao et al. 2018), *Giardia* (Xiao et al. 2013; Xiao et al. 2018), and endotoxin (De Man et al. 2014a), among others. These contaminated recreational water bodies can pose a potential threat to human health, including acute gastroenteritis and respiratory and skin diseases (World Health Organization 2003). However, relevant standards for such water bodies are missing or unclear in China.

Cryptosporidium and *Giardia* are highly resistant to environmental stress and can survive longer than indicator bacteria (Xiao et al. 2018). These protozoa have been detected in source water (Hu et al. 2014), reclaimed water (Zhang et al. 2015), and recreational water (Xiao et al. 2018). Over one hundred waterborne disease outbreaks associated with *Cryptosporidium* and *Giardia* have been reported in the last decade (Efstratiou et al. 2017; Rosado-Garcia et al. 2017). Therefore, the health risks posed by *Cryptosporidium* and *Giardia* in recreational water bodies to urban residents is of great significance and the need for a comprehensive evaluation cannot be overemphasized. Quantitative microbial risk assessment (QMRA) can be applied to evaluate the health risk of urban residents' exposure to specific pathogenic microorganisms in recreational water activities (De Man et al. 2014b; Vergara et al. 2016; Xiao et al. 2018). QMRA mainly comprise four steps, namely, hazard identification, exposure assessment, dose-response modeling, and risk characterization (Haas et al. 1999; Hamilton and Haas 2016).

Exposure assessment is the most critical step of the above four steps, incorporating exposure pathways and exposure parameters. Exposure parameters are used to evaluate the dose for human exposure to external substances through ingestion, inhalation and dermal contact, and they are particularly crucial for health risk assessment (EPA 2002). However, there are few reports of exposure assessment for the above recreational water activities, and there is no clear statement about the exposure parameters. Current studies mainly focus on monitoring the occurrence, concentrations, types, and infectivity of typical pathogenic microorganisms in recreational waters (De Man et al. 2014a; Dorevitch et al. 2015; Suppes et al. 2016; Vergara et al. 2016; Xiao et al. 2018). There are only a few reports on the relevant exposure parameters of recreational water activities for urban residents, including the single exposure duration and annual exposure frequency. In addition, there should be marked differences in the exposure parameters of the above recreational water activities for urban residents in Northern and Southern China, due to the differences in people's living habits, so it is also worthy of attention.

In this study, the exposure parameters, including the annual exposure frequency and single exposure duration for urban residents in swimming (SW), boating (BA), playing in interactive fountains (PF), and watching fountains (WF), were evaluated for ten representative cities in Northern and Southern China. QMRA for urban residents' exposure to *Cryptosporidium* and *Giardia* was also evaluated. Findings from this study provide a basis for the exposure parameterization and health risk management for urban residents in recreational water use in China.

Materials and methods

Sociodemographic characteristic of the respondents

In this study, 2001 adults in 10 China cities were interviewed in 2017. The surveyed cities were divided along the Qinling-Huaihe River Line (the geographical dividing line between Northern and Southern China) into six North cities —Anshan, Daqing, Xi'an, Tangshan, Shizuishan, and Zhengzhou—and four South cities, Yibin, Fuzhou, Guiyang, and Jinhua. The geographical location of the ten cities is shown in Fig. 1.

Respondents were ranged from 18 to 85 years old, with education levels including junior middle school and high school education, junior college, undergraduate, master's, and doctoral degrees. Occupations included farmers, students, personnel of administrative agencies and institutions, managers of landscape and recreational water bodies, cleaning and sanitation workers, teachers involved in environmental protection, and scientific researchers. Respondents were randomly selected in different areas of each city.

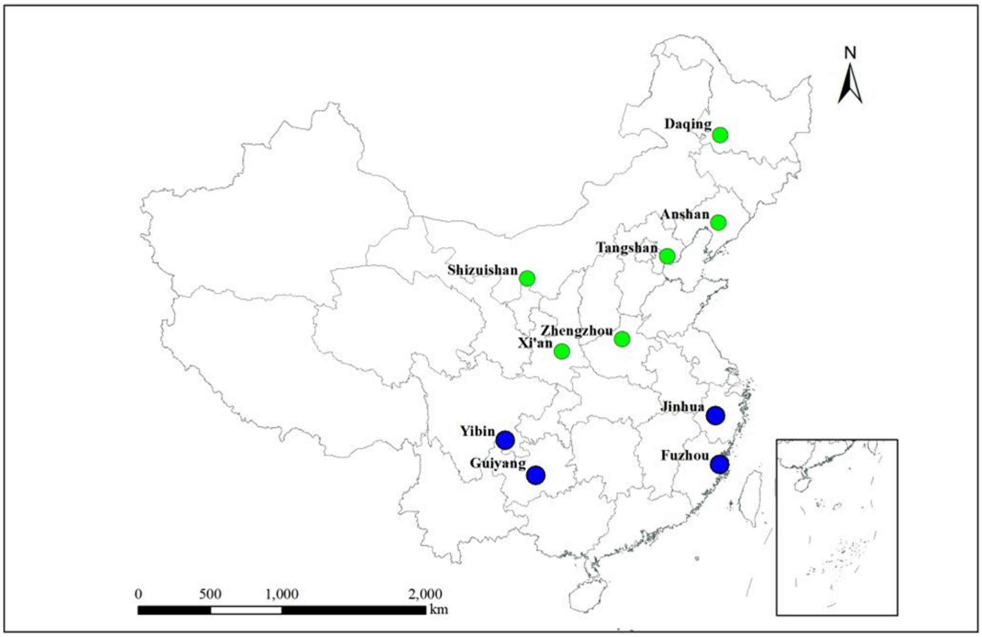

Fig. 1 Geographic locations of the survey cities in China. Note: The solid green circle represents North cities—Anshan, Daqing, Xi'an, Tangshan, Shizuishan, and Zhengzhou—the solid blue circle represents south cities, Yibin, Fuzhou, Guiyang, and Jinhua

Questionnaire description

A paper questionnaire was investigated by interviews in the study. All the surveyors were trained to ensure that they had the same understanding of each question. Basic information was included in this survey about the respondents: gender, age, occupation, education, etc. Four types of recreational water activities were surveyed, including SW, BA, PF, and WF. The annual exposure frequency and single exposure duration of recreational water activities were investigated as the key exposure parameters. Therefore, the exposure parameters of recreational water activities in this survey mainly include the annual exposure frequency and single exposure duration of SW; the annual exposure frequency and single exposure duration of BA; the annual exposure frequency and single exposure duration of PF; and the annual exposure frequency and single exposure duration of WF.

QMRA

QMRA was applicable to quantitatively calculate the health risk attributed to typical pathogenic microorganism (Hamilton and Haas 2016). It mainly consists of hazard identification, exposure assessment, dose-response model, and risk characterization (Haas et al. 1999).

Hazard identification

Cryptosporidiosis and giardiasis were the result from infection with the pathogenic microorganism *Cryptosporidium* and *Giardia* (Xiao et al. 2018), although they were not listed as candidate contaminant in the cases of diarrhea. They have been detected in water bodies, e.g., source water (Hu et al. 2014) and reclaimed water (Zhang et al. 2015), and recreational water (Xiao et al. 2018). At least more than one hundred waterborne outbreaks were associated with *Cryptosporidium* and *Giardia* in the last decade, respectively (Efstratiou et al. 2017; Rosado-Garcia et al. 2017).

Exposure assessment

The single exposure dose (D) of water ingestion volume containing *Cryptosporidium* or *Giardia* was estimated by Equations 1–4:

For the exposure scenario of SW,

$$D = C \times I_{SW} \times t_{SW} \times CF \tag{1}$$

where C represents the concentration of *Cryptosporidium* or *Giardia* ((oo)cysts/10L) in recreational water bodies, I_{SW} represents the water ingestion rate of swimming (mL/h), t_{SW} represents the single exposure duration of swimming (min), and CF represents conversion factors.

For BA,

$$D = C \times I_{BA} \times CF \tag{2}$$

where I_{BA} represents the water ingestion rate of BA (mL/visit).

For PF (De Man et al. 2014b),

$$D = C \times (h \times A \times f_{hA} + V_D \times f_D + IR \times VIWS) \times t_{IF} \times CF \tag{3}$$

where h represents the water thickness on hands (mm), A represents the skin area of the hand (mm^2), f_{hA} represents the frequency of hand to mouth contact (*n* per min), V_D represents the volume of droplets (μL), f_D represents the frequency of droplets in the mouth (*n* per min), *IR* represents the inhalation rate (m^3/min), *VIWS* represents the volume of inhalable water spray (μL/m^3), and t_{IF} represents the single exposure duration of playing in interactive fountains (min).

For WF (De Man et al. 2014b),

$$D = C \times IR \times VIWS \times t_{WF} \times CF \quad (4)$$

where t_{WF} represents the single exposure duration of watching fountains (min).

Dose-response model

The single infection risk ($P_{d,\ inf}$) for urban residents' exposure to *Cryptosporidium* and *Giardia* in the four recreational activities was calculated using the exponential dose-response model (Equation 5) (Xiao et al. 2018):

$$P_{d,inf} = 1 - e^{-r \times D} \quad (5)$$

where *r* was the infectivity per viable *Cryptosporidium* or *Giardia* concentration ingested, with a value of 0.09 for *Cryptosporidium* (Soller et al. 2010b) and 0.02 for *Giardia* (Soller et al. 2010b; Ehsan et al. 2015).

Risk characterization

The annual infection risk ($P_{y,\ inf}$) for urban residents' exposure to *Cryptosporidium* and *Giardia* in the four recreational water activities was calculated using Equation 6:

$$P_{y,inf} = 1 - \left(1 - P_{d,inf}\right)^n \quad (6)$$

where *n* represents the annual exposure frequency of the four recreational water activities, i.e., SW, BA, PF, and WF.

The total annual infection risk ($P_{y,\inf\_total}$) for urban residents' exposure to *Cryptosporidium* and *Giardia* in the four recreational water activities was calculated using Equation 7:

$$P_{y,inf\_total} = 1 - \prod_1^k \left(1 - P_{y,inf}\right) \quad (7)$$

where *k* represents the total number of the four recreational water activities.

Crystal Ball software was applied for risk calculation, and Monte Carlo method was used for 100,000 sampling calculations. Detailed calculated parameters applied for the health risk assessment are shown in Table 1.

Data analysis

All data were performed using Microsoft Office Excel 2013 and SPSS Statistics 23.0. A total of 2001 paper-based questionnaires

Table 1 Calculated parameters applied for the QMRA.

Parameters	Symbol	Assumptions	References
Concentration (/10L)	*C*		
Cryptosporidium oocyst		Lognorm (3.65, 3.54)	Xiao et al. 2018
Giardia cyst		Lognorm (12.58,8.35)	Xiao et al. 2018
Water ingested rate of swimming (mL/h)	I_{SW}		
Female		Lognorm (9.4,0.766)	Dufour et al. 2017
Male		Lognorm (16.4,1.78)	Dufour et al. 2017
Water ingested rate of BA (mL/visit)	I_{BA}	Lognorm(3.9,4.68)	Dorevitch et al. 2011
Water thickness on hands (mm)	*h*	Uniform(0.0197, 0.0234)	US EPA 2011
Skin area of hand (mm^2)	*A*	Uniform(100, 2000)	US EPA 2011
Frequency of hand to mouth contact (n per min)	f_{hA}	Gamma(2, 0.5)	Freeman et al. 2001
Volume of droplets (μL)	V_D	Uniform(0.5, 524)	De Man et al. 2014b
Frequency of droplets in mouth (*n* per min)	f_D	Gamma(2.1, 0.17)	De Man et al. 2014b
Inhalation rate (m^3/min)	*IR*		
Female		0.00101	Duan et al. 2014
Male		0.00122	Duan et al. 2014
Volume of inhalable water spray (μL/m^3)	*VIWS*	10.8	De Man et al. 2014a
Single exposure duration	*t*	Shown as Table 3	This study
Annual exposure frequency	*n*	Shown as Table 3	This study

were registered into the Excel, and questionnaires with missing quality or obvious logic test errors that did not meet the requirements were excluded, and valid questionnaires were collected. The exposure parameters of recreational water activities were extracted from the valid questionnaires and the data were summarized according to residents of different recreational water activities, South and North China, male and female, residents over 35 years old and 18–35-year-old residents. The independent parameter t test was used for the exposure parameters of different groups, based on statistical analysis. $p < 0.05$ was considered statistically significant. Statistics describing exposure parameters included mean, median, and four percentiles (P5, P25, P75, and P95). The exposure parameters of different recreational water activities were fitted to determine the optimal distribution by "Kolmogorov-Smirnov test."

The participation rate of recreational water activities for urban residents can be calculated by Equation 8:

$$P_r = \frac{N_i}{N_{total}} \times 100\% \quad (8)$$

where P_r represents the participation rate of recreational water activities (%), N_i represents the number of respondents participating in the recreational water activities, and N_{total} represents the total number of the respondents.

Results

Descriptive parameters

Paper-based questionnaires were investigated in 10 cities of China. A total of 1610 valid questionnaires (80.5%) were obtained among these 2001 respondents, and there were 1065 questionnaires in Northern China and 545 questionnaires in Southern China. The gender distribution ratio of the respondents (North, male 52.1%, female 47.9%; South, male 53.9%, female 46.1 %;) was consistent with the overall population distribution in China (male, 52%; female, 48%), indicating that the data were representative.

Among these respondents, the proportion of 18–35-year-old residents was 54.1%, while over 35 years old was 45.9%. The majority of respondents were undergraduates (41.9%) with a high level of education (Table 2). Respondents were engaged in various occupations, among which students account for the highest, while farmers the lowest (not shown in this study).

Table 2 Sociodemographic characteristics of the surveyed respondents

Factor	Classification	Number		
		North	South	Total
Gender	Male	555	294	849
	Female	510	251	761
Age	18–35	590	278	868
	≥ 35	475	267	742
Educational level	High school and under	403	199	602
	Associate degree	185	80	265
	Undergraduate	439	236	675
	Master's and doctoral degrees	38	30	68

Exposure parameters

Exposure parameters of different recreational water activities

Among the respondents, 494 (58.2%), 272 (32.0%), 120 (14.1%), and 344 (40.5%) of adult male participated in the exposure scenario of SW, BA, PF, and WF, respectively; 330 (43.4%), 298 (39.2%), 135 (17.7%), and 340 (44.7%) of adult female participated in the exposure scenario of SW, BA, PF, and WF, respectively (Fig. 2). Obviously, the participation level for male in the four recreational water activities was shown as follows, SW > WF > BA > PF, while for female was shown as follows: WF > SW > BA > PF.

Comparison for exposure parameters in North and South China

The exposure parameters of the recreational water activities for urban residents in Northern and Southern China are shown in Fig. 3. The median value of annual exposure frequency in Northern China was almost equal to Southern China, while the median value of single exposure duration in Northern China was higher than that of Southern China. The proportion of residents participating in SW in Southern China was

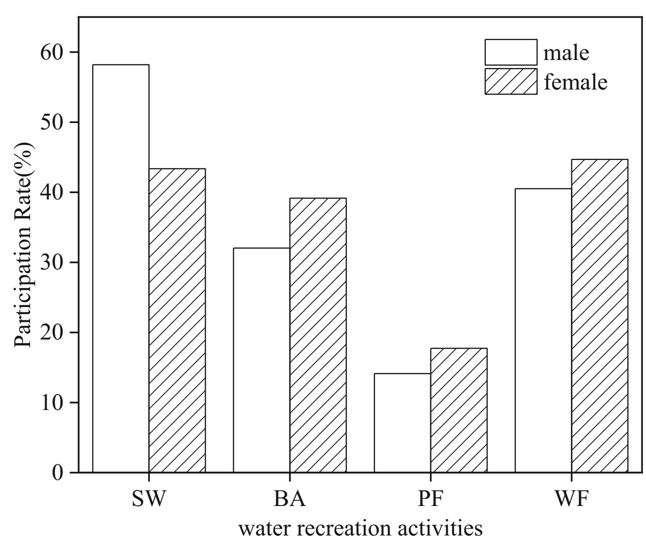

Fig. 2 Participation rate in the recreational water activities. Note: SW: male, $n = 494$; female, $n = 330$; BA: male, $n = 272$; female, $n = 298$; PF: male, $n = 120$; female, $n = 135$; WF: male, $n = 344$; female, $n = 340$

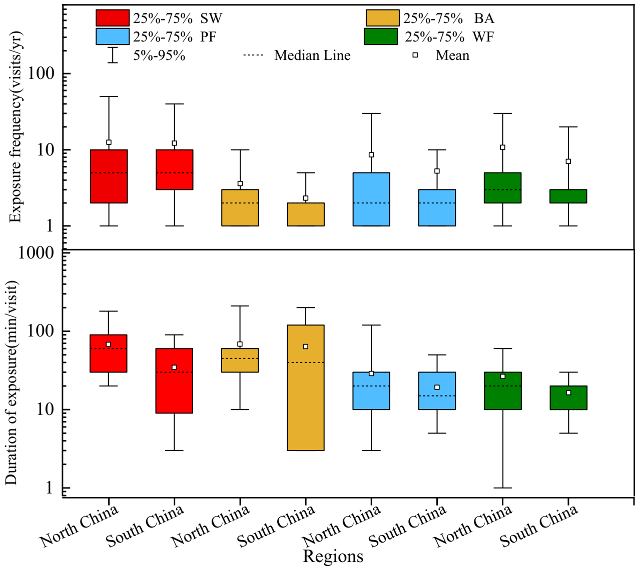

Fig. 3 Exposure parameters for participants of North and South China. Note: SW: North China, n = 506; South China, n = 318; BA: North China, n = 365; South China, n = 205; PF: North China, n = 170; South China, n = 85; WF: North China, n = 498; South China, n = 186

70.1%, which was higher than of Northern China (49.4%). The exposure frequency of SW for residents in Northern China was 12 visits/year, which was equal to Southern China, while the mean single exposure duration of SW in Northern China (67.8 min/visit) was significantly higher than that of Southern China (34.6 min/visit) ($p < 0.01$). In addition, the mean annual exposure frequency and single exposure duration in other exposure scenario, i.e., BA, PF, and WF, were higher in Northern China than those in Southern China. Moreover, there was a significant difference in the single exposure duration of PF and WF for Northern and Southern China ($p < 0.01$).

Comparison for exposure parameters of female and male

The exposure parameters of four recreational water activities for male and female are shown in Fig. 4. The median value of single exposure duration for male in SW, BA, and WF was higher than that of female, while this in PF was on the contrary. For SW, the mean exposure frequency for male (15.9 visits/year) was significantly higher than that of female (7.2 visits/year) ($p < 0.05$), and the mean exposure duration for male was 57.4 min/visit, which was 5.6 min higher than that of female (51.8 min/visit), with no significant difference ($p = 0.144 > 0.05$). For BA, the mean exposure frequency (3.8 visits/year) and exposure duration (66.3 min/visit) for male were higher than those of females, with a significant difference for annual exposure frequency ($p < 0.01$), while no significant difference for single exposure duration ($p = 0.488 > 0.05$). However, the annual exposure frequency and single exposure duration for male were less than those of female in

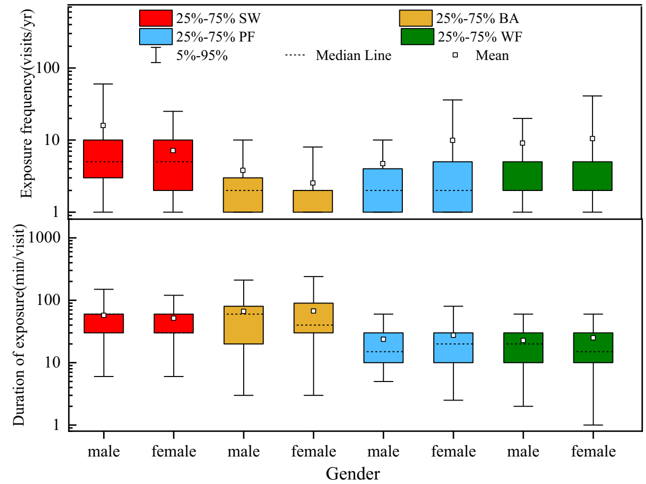

Fig. 4 Exposure parameters for participants of male and female. Note: SW: male, n = 494; female, n = 330; BA: male, n = 272; female, n = 298; PF: male, n = 120; female, n = 135; WF: male, n = 344; female, n = 340.

the exposure scenario of PF and WF. The mean exposure frequency of PF for female (7.9 visits/year) was 2 visits higher than that of male (5.9 visits/year) ($p = 0.01 < 0.05$). In addition, there was no significant difference for the mean annual exposure frequency of WF between female and male ($p = 0.365 > 0.05$), while there was a significant difference for the mean single exposure duration ($p = 0.046 < 0.05$).

Comparison for exposure parameters of different age groups

The exposure parameters for urban residents of different age groups in recreational water activities are shown in Fig. 5. The mean exposure frequency and exposure duration for 18–35-year-old residents participating in the four recreational activities are shown as follows: SW 11.0 visits/year, 57.6 min/

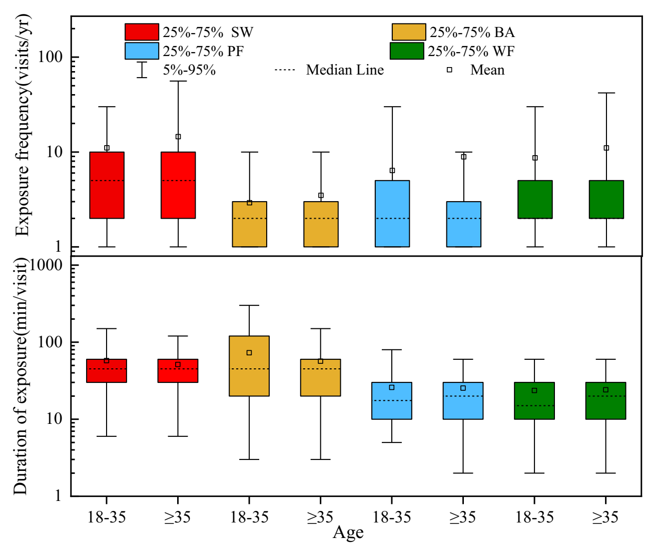

Fig. 5 Exposure parameters for participants of different age groups. Note: SW: 18–35, n = 502; ≥ 35, n = 322; BA: 18–35, n = 358; ≥ 35, n = 212; PF: 18–35, n = 159; ≥ 35, n = 98; WF, 18–35, n = 369; ≥ 35, n = 315

Table 3 Exposure parameter distribution for urban residents in the recreational water activities

Recreational Water activities	Exposure parameters	Parameter (μ, σ)	Gender		Region	
			Male (μ, σ)	Female (μ, σ)	North China (μ, σ)	South China (μ, σ)
SW	Exposure frequency (visits/year)	(12.4, 29.7)	(15.9, 37.3)	(7.2, 8.3)	(12.5, 30.6)	(12.2, 28.2)
	Single exposure duration (min/visit)	(55.2, 46.8)	(57.4, 49.0)	(51.8, 43.1)	(67.8, 51.4)	(34.6, 28.1)
BA	Exposure frequency (visits/year)	(3.1, 6.6)	(3.8, 9.0)	(2.5, 3.1)	(3.6, 8.1)	(2.3, 2.3)
	Single exposure duration (min/visit)	(66.8, 74.4)	(66.3, 74.1)	(67.2, 74.8)	(68.5, 73.0)	(63.7, 77.1)
PF	Exposure frequency (visits/year)	(6.9, 16.2)	(5.9, 12.4)	(7.9, 19.1)	(8.6, 30.3)	(5.3, 16.0)
	Single exposure duration (min/visit)	(26.2, 26.1)	(25.0, 24.6)	(27.3, 27.4)	(28.9, 31.7)	(19.3, 13.0)
WF	Exposure frequency (visits/year)	(11.3, 38.9)	(10.1, 38.1)	(12.5, 40.1)	(10.8, 36.8)	(7.0, 23.0)
	Single exposure duration (min/visit)	(23.4, 23.7)	(22.7, 21.6)	(24.8, 43.9)	(26.5, 39.0)	(16.4, 15.3)

visit; BA 2.9 visits/year, 72.9 min/visit; PF 6.4 visits/year, 25.9 min/visit; and WF 8.7 visits/year, 23.6 min/visit. For residents over 35 years old, the mean exposure frequency and exposure duration participating in these recreational water activities shown as follows: SW 14.5 visits/year, 51.4 min/visit; BA 3.5 visits/year, 56.5 min/visit; PF 8.9 visits/year, 25.4 min/visit; and WF 11 visits/year, 24 min/visit. The mean annual exposure frequency for residents over 35 years old was higher than 18–35 years residents, with no significant difference as for median values. In contrast, the mean single exposure duration for residents over 35 years old was lower than 18–35-year-old residents, except for WF. This was mainly related to the work and free time, the interest, and physical strength for respondents of different ages participating in recreational water activities.

Exposure parameters distribution

The distribution of exposure parameters was of great significance for health risk assessment. Several standard distributions, e.g., normal, lognormal, uniform, and Gamma and Beta distributions, were selected to fit the exposure parameters for urban residents in recreational water activities, and the fittest distribution is shown at Table 3. Overall, the exposure parameters for urban residents were followed to the lognormal distribution, including the four recreational water activities, male and female, and South and North China.

Health risk assessment

The annual infection risk ($P_{y,\ inf}$) for urban residents exposure to *Cryptosporidium* and *Giardia* in the recreational water activities is shown in Table 4. The mean value of the total annual infection risk ($P_{y,\ inf\ \_\ total}$) for male and female exposure to *Cryptosporidium* in the four recreational water activities was 1.0×10^{-2} and 6.8×10^{-3}, with confidence intervals between 95 and 5% was [4.3×10^{-4}, 3.7×10^{-2}] and [4.2×10^{-4}, 2.4×10^{-2}], respectively, and the mean $P_{y,\ \mathrm{inf}\ \_\ total}$ for male and female exposure to *Giardia* in the four recreational water activities was 8.8×10^{-3} and 5.3×10^{-3}, with confidence intervals between 95 and 5% was [5.1×10^{-4}, 3.2×10^{-2}] and [4.0×10^{-4}, 1.8×10^{-2}], respectively.

For the exposure scenario of SW, the mean $P_{y,\ inf}$ for male and female exposure to *Cryptosporidium* was 6.1×10^{-3} and

Table 4 The annual infection risk ($P_{y,\ inf}$) for urban residents exposure to *Cryptosporidium* and *Giardia* in the recreational water activities ($\times 10^{-4}$)

$P_{y,\ inf}$	Cryptosporidiosis								Giardiasis							
	Male				Female				Male				Female			
	Mean	5%	50%	95%	Mean	5%	50%	95%	Mean	5%	50%	95%	Mean	5%	50%	95%
SW	61	247	12	0.5	19	73	6.9	0.7	60	240	15	1.0	15	54	6.1	0.7
BA	4.7	18	0.9	0.04	3.2	12	0.9	0.07	3.7	14	0.8	0.04	2.5	9.5	0.8	0.07
PF	33	128	6.2	0.3	47	190	7.9	0.3	26	103	5.6	0.3	38	149	7.1	0.3
WF	0.001	0.003	0.0001	0.000005	0.001	0.004	0.0001	0.000005	0.0008	0.003	0.0001	0.000005	0.0008	0.003	0.0001	0.000004
Total	101	374	35	4.4	69	239	27	4.3	88	322	36	5.1	53	181	23	4.0

Note: 5% and 95% means confidence interval. 50% mean the median value. $P_{y,\ inf}$ represents the annual exposure risk of infection

1.9×10^{-3}, with confidence intervals between 95 and 5% was [5.5×10^{-5}, 2.5×10^{-2}] and [6.5×10^{-5}, 7.2×10^{-3}], respectively, and the mean $P_{y,\ inf}$ for male and female exposure to *Giardia* was 6.0×10^{-3} and 1.5×10^{-3}, with confidence intervals between 95 and 5% was [1.0×10^{-4}, 2.4×10^{-2}] and [7.0×10^{-5}, 5.4×10^{-3}], respectively.

For the exposure scenario of BA, the mean $P_{y,\ inf}$ for male and female exposure to *Cryptosporidium* was 4.7×10^{-4} and 3.2×10^{-4}, with confidence intervals between 95 and 5% was [4.1×10^{-6}, 1.8×10^{-3}] and [6.9×10^{-6}, 1.2×10^{-3}], respectively, and the mean $P_{y,\ inf}$ for male and female exposure to *Giardia* was 3.7×10^{-4} and 2.5×10^{-4}, with confidence intervals between 95 and 5% was [4.2×10^{-6}, 1.4×10^{-3}] and [7.2×10^{-6}, 9.5×10^{-4}], respectively.

For the exposure scenario of PF, the mean $P_{y,\ inf}$ for male and female exposure to *Cryptosporidium* was 3.3×10^{-3} and 4.7×10^{-3}, with confidence intervals between 95 and 5% was [2.6×10^{-5}, 1.3×10^{-2}] and [3.1×10^{-5}, 1.9×10^{-2}], respectively, and the mean $P_{y,\ inf}$ for male and female exposure to *Giardia* was 2.6×10^{-3} and 3.8×10^{-3}, with confidence intervals between 95 and 5% was [2.7×10^{-5}, 1.0×10^{-2}] and [3.1×10^{-5}, 1.5×10^{-2}], respectively.

For the exposure scenario of WF, the mean $P_{y,\ inf}$ for male and female exposure to *Cryptosporidium* was 1.0×10^{-7} and 1.1×10^{-7}, with confidence intervals between 95 and 5% was [5.0×10^{-10}, 3.6×10^{-7}] and [4.0×10^{-10}, 3.9×10^{-7}], respectively, and the mean $P_{y,\ inf}$ for male and female exposure to *Giardia* was 8.0×10^{-8} and 8.5×10^{-8}, with confidence intervals between 95 and 5% was [5.0×10^{-10}, 2.9×10^{-7}] and [4.0×10^{-10}, 3.0×10^{-7}], respectively.

In addition, the sensitivity analysis showed that P_{y, inf_total} for male and female exposure to *Cryptosporidium* and *Giardia* was most affected by the annual exposure frequency (n), the single exposure duration (t), and the concentration of *Cryptosporidium* and *Giardia* (Fig. 6). Specifically, there was the annual exposure frequency and single exposure duration of SW and PF.

Discussion

Exposure parameters

The results of this study indicate notable differences in the annual exposure frequency and single exposure duration to recreational water activities by region, gender, and age. The main reasons for the regional differences between North and South China could be attributed to geographical location, climate characteristics and residents' living habits. Conversely, the differences between residents over 35 years old and those

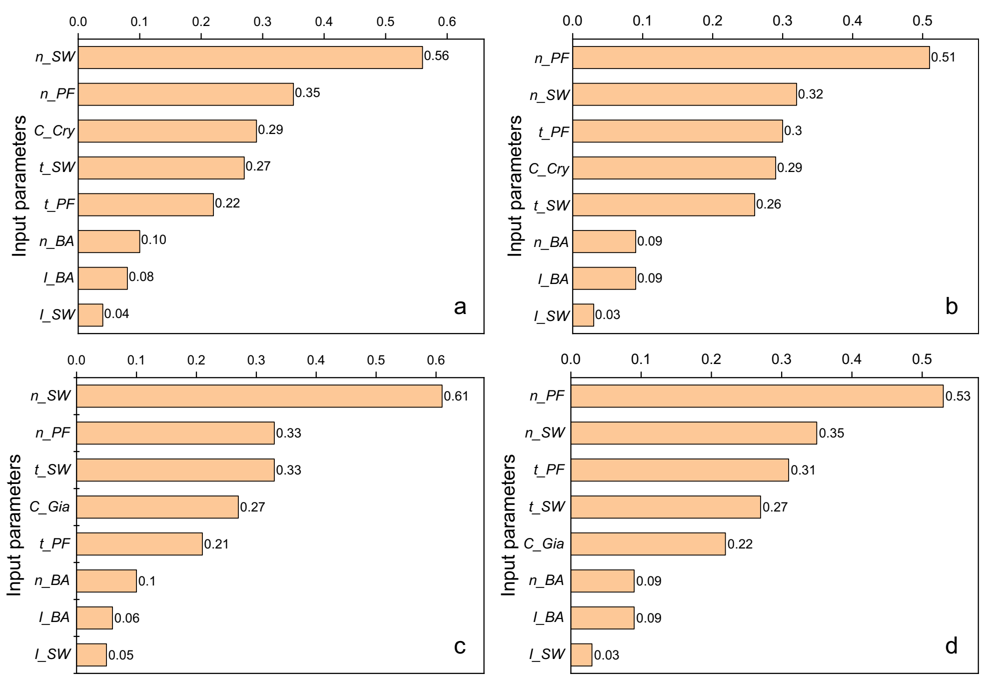

Fig. 6 Sensitivity by computing rank order correlation coefficients between the parameters and the annual infection risk ($P_{y,\ inf}$) caused by *Cryptosporidium* and *Giardia* in recreational water activities. Note: **a** the total annual infection risk of cryptosporidiosis for male caused by *Cryptosporidium*; **b** the total annual infection risk of cryptosporidiosis for female caused by *Cryptosporidium*; **c** the total annual infection risk of giardiasis for male caused by *Giardia*; **d** the total annual infection risk of giardiasis for female caused by *Giardia*. *C_Cry* represents the concentration of *Cryptosporidium*; *C_Gia* represents the concentration of *Giardia*; *n_SW* represents the annual exposure frequency of swimming; *n_BA* represents the annual exposure frequency of BA; *n_PF* represents the annual exposure frequency of playing in interactive fountains; *t_SW* represents the single exposure duration of swimming; *t_PF* represents the single exposure duration of playing in interactive fountains; *I_SW* represents the water ingestion rate of swimming; *I_BA* represents the water ingestion rate of BA

of 18–35-year-old residents could be explained by the type of work and amount of free time of respondents, their interests, and physical strength. Residents aged between 18 and 35 may be busy with work and study, and they can only participate in these activities on weekends or statutory holidays, albeit for longer periods on each occasion. For residents over 35 years old, some are over 60 years old, who are retired residents; they may be retired with more leisure time so that the frequency of participation was higher. However, due to their relatively weak physical strength and diminishing interest, the single exposure duration was less than that of residents between 18 and 35 years old. Besides, the exposure parameters conformed to a lognormal distribution, which was similar to that reported in previous studies (Hoebe et al. 2004; Dorevitch et al. 2011; Sunger et al. 2012; Suppes et al. 2016).

For the exposure scenario of SW, the mean exposure frequency and exposure duration were 12.4 visits/year and 55.2 min/visit, respectively. The single exposure duration for urban residents (55.2 min) was higher than those reported for the USA (45 min) (EPA 2002), South Korea (male, 14.8 min; female, 26.8 min) (Jang et al. 2014), and Japan (53.7 min) (Gamo and Futatsumata 2006). Nonetheless, this duration was lower than that reported for the Netherlands (swimming pool: 13~24 visits/year, 67–81 min/visit; urban water and seawater: 6~8 visits/year, 41~79 min/visit) (Schets et al. 2011). For the exposure scenario of BA, water ingestion rate for residents (3.8 mL/visit) (McBride et al. 2013), exposure dose, and frequency for surfers (170 mL/d and 77 d/year) (Stone et al. 2008) were investigated. In addition, the health risk for recreational water activities through the incidence of gastroenteritis have been estimated, while the annual exposure frequency and single exposure duration were not included (Rijal et al. 2011; Dorevitch et al. 2012).

The single exposure duration for US residents in the exposure scenario of PF was 0.5–2.5 h, with a mean exposure duration of 1.6 h and water ingestion rate of 7.04 mL/h (Hoebe et al. 2004). The exposure duration for residents was also investigated by real-time photography, and the following results were obtained: Delaware River, 14 min/visit, 17 min/visit; Creeks, 8 min/visit; 22 min/visit (Sunger et al. 2012). Similarly, an investigation of an interactive fountain using rainwater as source water was carried out by De Man et al. (2014b). The results showed a mean exposure duration for residents of 3.5 min/visit and ranging from 1 to 120 min, which was lower than that of this study. Moreover, people can be infected by protozoa contained in the water via fountain sprays, which caused outbreaks of giardiasis and cryptosporidiosis (Eisenstein et al. 2008; Xiao et al. 2018).

However, a drawback of collecting exposure parameters through questionnaires completed by respondents was that bias can be easily introduced, and these data were difficult to identify and exclude. In the process of the questionnaire survey, respondents' answers to the annual exposure frequency and single exposure duration depend on their memory entirely. So, these data may be blurred due to poor memory, and deviate from actual conditions, leading to over- or underestimation of the actual exposure parameters. Nonetheless, although the questionnaires in this study may obtain biased data, it still provides insight into the exposure frequency and single exposure duration for urban residents in recreational water activities. It also provides exposure parameters, which were previously lacking for health risk assessment. As a fact, water droplets and aerosols can be ingested or inhaled by urban residents when participating in recreational water activities. Thus, pathogenic microorganisms contained in the recreational water will pose a threat to the health of the human body (De Man et al. 2014b; Xiao et al. 2018). Therefore, it was significantly important to obtain the exposure parameters for urban residents in recreational water activities, to evaluate the corresponding health risk.

Health risk assessment

Overall, the annual infection risk ($P_{y,\ inf}$) for male exposure to *Cryptosporidium* and *Giardia* in the exposure scenario of SW was the highest among the four recreational water activities, while for females, it was PF. Besides, $P_{y,\ inf}$ for male and female exposure to *Cryptosporidium* and *Giardia* in the exposure scenario of WF was the lowest. In addition, $P_{y,\ inf}$ for male exposure to *Cryptosporidium* and *Giardia* were higher than that for females in the exposure scenario of SW and BA, whereas those for the exposure scenarios of PF and WF were the opposite. These results were related to the exposure dose, including exposure parameters ("Exposure parameters" section), the concentration of *Cryptosporidium* and *Giardia*, and volume of water ingestion (Table 1). Moreover, $P_{y,\ inf}$ for urban resident's exposure to *Cryptosporidium* were higher than that of urban resident's exposure to *Giardia* in all four exposure scenario of SW, BA, PF, and WF.

Currently, there is an authoritative standard proposed by the Dutch Ministry of Infrastructure and Environment, stating the acceptable guideline of one infection per 10,000 persons per year for exposure to enteric pathogens by un-boiled water ingestion (De Man et al. 2014b). Therefore, an annual infection risk benchmark of 0.0001 per person per year (pppy) is recommended in this study (De Man et al. 2014b; Hamilton et al. 2018; Pepper and Gerba 2018). The results show that $P_{y,\ inf}$ of cryptosporidiosis and giardiasis for urban resident's exposure to *Cryptosporidium* and *Giardia* exceeded this benchmark, except for WF. The recovery efficiency of *Cryptosporidium* and *Giardia* was not taken into account in this study, which undoubtedly underestimated the health risk to a certain extent (Xiao et al. 2018).

The single exposure duration (t) and annual exposure frequency (n) were critical parameters to determine the infection risk, based on sensitivity analysis (Xiao et al. 2018). In this study, QMRA was estimated based on the single exposure duration and annual exposure frequency, which was investigated by the questionnaire survey. The results indicate that the exposure scenario of SW and PF attribute most to P_{y,inf_total} for urban residents' exposure to *Cryptosporidium* and *Giardia* in the four recreational water activities. Besides, the annual exposure frequency of BA and the water ingestion rate of BA and SW were also important factors. Therefore, it was necessary to collect and summarize the above exposure parameters as such studies would provide a further in-depth risk assessment of exposure to specific pathogenic microorganisms in recreational water activities.

Conclusions

Exposure parameters and health risks of *Cryptosporidium* and *Giardia* in the recreational water activities for urban residents were investigated in this study. The main conclusions are shown as follows:

– The participation rates of urban residents in SW and WF were higher than the other recreational water activities.
– In SW and BA, the mean exposure parameters for males were significantly higher than those for females while those in PF and WF were the opposite. The annual exposure frequency for residents above 35 years old was higher than young residents (18–35 years). By contrast, the single exposure duration of young residents was higher in SW, BA, and PF. Those parameters for North China residents were higher than South China residents in all recreational water activities, except for SW.
– For urban residents, the exposure parameters in recreational water activities all followed a lognormal distribution.
– For urban residents, the annual infection risk exceeded the benchmark of 0.0001 pppy in SW, BA, and PF. Nonetheless, SW and PF made the greatest contribution to the total annual infection risk.

Therefore, it is meaningful to investigate the exposure parameters for urban resident's participation in recreational water activities, as these exposure parameters play a critical role in the health risk assessment. Nonetheless, future work to refine the exposure parameters is necessary, as this would provide further in-depth health risk assessment.

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Authors' contributions Chong-Miao Zhang: Conceptualization, methodology, writing, supervision—original draft
Peng-Cheng Xu: Investigation, writing
Wei-Wei Du: Investigation, writing
Xiaochang C. Wang: Supervision

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Declarations

Ethics approval and consent to participate Not applicable.

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