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Risk assessment of *Giardia* in rivers of southern China based on continuous monitoring

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Abstract

The occurrence and risks of *Giardia* in China have been unclear to date, which has made it difficult to properly manage source water as well as to create reasonable drinking water standards. The levels of *Giardia* in river networks of several cities in Zhejiang Province, China were found to be in the range of 0–5 oocysts/10 L in the rainy season in 2008. The mortality due to *Giardia* infection for people in this region was calculated to be from 0 to 1.95×10^{-8} persons using a conditional probability equation. Based on multiple unboiled water intake routes, the disability-adjusted life years (DALYs) due to *Giardia* infection for people who consumed conventionally treated water was 0.625 (95% CI: 0.137–2.05) per 10^5 persons, with the symptom of hospitalization making the highest contribution to total DALYs (0.56 per 10^5 persons; 95% CI: 0.122–1.84). The DALYs decreased to 0.425 (95% CI: 0.137–2.05) per 10^5 persons per year for those consuming water treated with advanced technology. These values were lower than the acceptable risk (1.97×10^{-5} DALYs per year). This study revealed the risk of *Giardia* infection to the people in river networks of Zhejiang Province for the first time, and provides a method to evaluate the risk of *Giardia* infection. The results are useful for the modification of drinking water quality standards based on cost-benefit analysis.

Key words: *Giardia*; risk assessment; water consumption; disability-adjusted life years

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Introduction

Giardiasis infection leading to symptoms including gastroenteritis and abdominal distention is a common waterborne disease in many countries. *Giardia* can spread between persons and animals through fecal-oral transmission. There are about 2,500,000 cases, or one for every 100 persons per year, in the United States (Rockwell, 2003). In some countries, including China, giardiasis is listed in the drinking water standards.

Several studies have highlighted the health risk assessment of *Giardia* using the annual individual probability of infection, which has also been used for *Cryptosporidium* (Jolis et al., 1999; Cummins et al., 2010). *Giardia* has high infectivity (Gibson et al., 1998), while the symptoms are generally relatively mild comparing with that of *Cryptosporidium* (US EPA, 1999). Thus, it is impossible to compare their relative risks only based on infection probability. The method of disability-adjusted life years (DALYs) provides a unified assessment measurement using time as a uniform unit (Vijgen et al., 2007) by integrating the different symptoms of adverse health effects (Havelaar et al., 2000), which has been used to assess the health risk of *Giardia*. However, previous risk assessments of *Giardia* have ignored mortality when calculating DALYs (Bennett et al., 1987), which led to the underestimation of risk. In fact, *Giardia* infection cannot only result in gastroenteritis, abdominal cramps, vomiting, and growth impairment, but also death. In 1982, giardiasis was listed as the underlying cause for four deaths in the United States (US EPA, 1999). Giardiasis can also cause death through complications in malnourished children (Mukherjee and Johnston, 2009) or pneumonia patients (LOPH, 2009). However, mortality from giardiasis is typically underreported in most routine surveillance systems (Vijgen et al., 2007). Thus, there is little information available regarding death caused indirectly by *Giardia* infection, particularly through gastroenteritis complications.

There are different intake routes of *Giardia,* including direct consumption, tooth brushing, dishes, and swimming in rivers. However, most previous studies only considered drinking as the exposure route, which can also cause the underestimation of infection risks. In this study, the *Giardia* concentrations in the source water of several cities of Zhejiang Province, China were continuously monitored during the rainy season of 2008, and then the risk of *Giardia* infection was calculated by considering the cause-specific mortality of fatal gastroenteritis caused by *Giardia*

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infection and multiple potential exposure routes. The results of this study will be useful for the modification of drinking water quality standards of China.

1 Materials and methods

1.1 Water sampling and *Giardia* detection

During the rainy season (June to September) of 2008, samples were collected from the Jiaxing, Yuyao, Tongxiang and Xiaoshan rivers, as shown in Fig. S1 in supporting information. The volume of each sample was ten liters, and the samples were filtered within four hours of sampling. Two samples were collected from the Jiaxing, Yuyao, and Xiaoshan rivers from 8 July to 12 July and on August 29, respectively. In Tongxiang, samples were collected daily from 19 to 29 August.

The detection of *Giardia* was conducted according to the method described by Hashimoto et al. (2002). The density distribution of the concentration for *Giardia* was fitted by different probability density functions, i.e. exponential, uniform, lognormal, and normal function using STATISTICA (data analysis software system), version 8.0 (StatSoft, Inc., 2007). Of these, the best goodness-of-fit was selected according to their p-value and χ^2 test value.

1.2 Exposure assessment

The probability of *Giardia* infection is related to its contamination level in different routes. In this study, three main exposure routes were considered: direct drinking tap water, intake by residues from tooth-brushing and washing, and swallow by swimming in rivers.

The daily consumption of water in China is about 1.75 L per person, while that of other countries generally ranges from 0.25 to 1.1 L (Teunis et al., 1997; Gale 2001; Hoornstra and Hartog 2003; Westrell et al., 2003; Heyworth et al., 2006; Masago et al., 2006). It should be noted that drinking boiled water and eating heated food is popular in China. In Zhejiang Province, only about 0.8% of people drink tap water directly (Xu et al., 2008). The ingestion volume from residues, was firstly estimated to be 0.007–0.071 L/(person·day), including adsorbed water on the mouth after tooth-brushing and food and dish after washing (An et al., 2011). The accidental intake volume of a person swimming in a river was about 0.016–0.037 L of surface water (Dufour et al., 2006), and about 10.5%–21.6% of the population swim in the rivers (Bureau, 2005). The frequency of swimming was assumed to be once a week over a 5-month period from May to September (i.e., 20 times/year). Removal of cysts by conventional treatment waterworks was about 2–2.5 $\log_{10}$ units, whereas advanced treatments combining ozone and conventional treatment had an expected efficiency of 4–4.5 $\log_{10}$ units (WHO, 2009).

1.3 Dose–response of *Giardia* infection and uncertainty analysis

The exponential models used to fit the dose–response data of *Giardia* infection were as Eq. (1):

$$P_{\text{in}} = 1 - e^{-r \times D} \tag{1}$$

where, P_{in} is the probability of infection; r is a scale factor for the dose, of which the value was 0.01982 with a 95% confidence interval of 0.009798 to 0.03582 (Rose et al., 1991), and D is the ingested dose of *Giardia*. The uncertainty analysis in this study included parameter fluctuations, which were conducted by the Monte Carlo method (Crystall Ball 2000 Professional; Decisioneering, USA).

1.4 Calculation of DALYs

The adverse effects of contaminants can reduce the length and quality of life. This reduction can be measured by the disability-adjusted life years (DALYs) (Murray and Lopez, 1997). DALYs are the sum of lost life-years (LYL) due to mortality and those lost by living with disability (YLD). YLD can be estimated by Eq. (2):

$$\text{YLD} = \sum_{i}^{n} \sum_{j}^{m} \alpha_j N_i L_i W_j \tag{2}$$

where, N is the number of individuals affected by a non-lethal disease; L is the duration of the disease, and W is the measure of its severity, weighed with a factor between 0 and 1. α represents the portion of individuals with different severities of gastroenteritis. Gastroenteritis due to *Giardia* was divided into three severities (j): slight symptoms, i.e. no need to seek treatment (No-GP), need to visit a general practitioner (GP), and hospitalization.

The lost life-years (LYL) were calculated by Eq. (3):

$$\text{LYL} = \sum_{i}^{n} d_i \text{E}_i \tag{3}$$

where, i is the age in the special population, d_i is the amount of deaths due to the disease at age i, and E_i is the standard life expectancy at age i.

In this study, the mortality rate associated with *Giardia* infection ($P_{\text{f\_giar}}$) was calculated by multiplying the mortality due to gastroenteritis (P(f|g)) by the incidence of gastroenteritis (P_{in} in Eq. (1)) caused by *Giardia* infection. The mortality rate from gastroenteritis (P(f|g)) can be calculated by the quotient of the probability of fatal gastroenteritis (P(f,g)) and the incidence of gastroenteritis (P(g)) (An et al., 2011).

2 Results and discussion

2.1 Exposure assessment of *Giardia*

The frequency density distribution of *Giardia* in source water of the surveyed region is shown in Fig. 1. The average concentration was found to be 1 oocyst/10 L. The highest concentration of 5 oocysts/10 L was observed once, and zero oocysts/10 L frequently occurred with thirteen times. This level was similar with the results of previous studies. For example, the concentration of

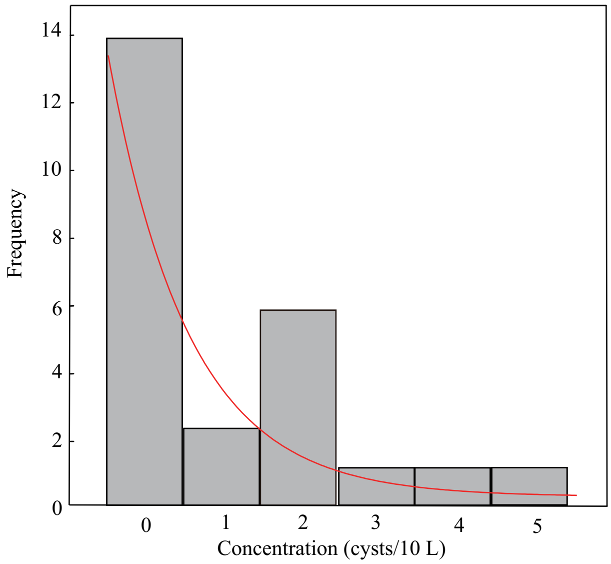

Fig. 1 Frequency distribution for *Giardia* in 10 L of surface water.

Giardia cysts were detected to be from 0.03 to 10 cysts/10 L with in 26%–92% raw water of Japan and United States (Rose et al., 1991; Hashimoto et al., 2002). Much higher concentration was found from 1 to 125 cysts/10 L in rivers of Chengdu and Guangzhou, China (Cai et al., 2008; Wang et al., 2008).

Exponential distribution models were used to fit the levels of *Giardia* (Fig. 1), and the lowest χ^2 test value observed was 3.584 (p = 0.05832). Equation (4) was used to describe the probability distribution of *Giardia* in the investigated region:

$$\mathrm{Pr}(C_{\mathrm{cry}}) = 0.99 \times \mathrm{e}^{-0.99 \times C_{\mathrm{giar}}} \tag{4}$$

where, Pr is the probability distribution of *Giardia* occurrence and C_{giar} (count/10 L) is the concentration of *Giardia*. The annual dose (D_{a}) can be calculated by Eq. (5).

$$D_{\mathrm{a}} = C_{\mathrm{giar}} \times \phi \times V_{\mathrm{d}} \times T \tag{5}$$

where, ϕ (%)is the *Giardia* removal efficiency in drinking water treatment, T (day) is the duration at a *Giardia* exposure, and V_{d} (L/(day·person)) is the daily intake volume of water (An et al., 2011).

2.2 Mortality caused by *Giardia*

The major symptom of giardiasis is gastroenteritis, which can induce death by complications such as dehydration, hypernatraemia, and hypophosphataemia. The mortality ($P_{\mathrm{f\_giar}}$) induced by gastroenteritis for *Giardia* infection was estimated based on the cause-specific mortality as Eq. (6):

$$P_{\mathrm{f\_giar}} = \frac{\mathrm{P(f,g)}}{\mathrm{P(g)}} \times (1 - \mathrm{e}^{-0.01982 \times D}) \tag{6}$$

where, fatal gastroenteritis (P(f,g)) was reported in Yearbook of Health in the People's Republic of China (Li and Hu, 2007) as shown in Table S1 in supporting information and incidence of gastroenteritis (P(g)) in China is as previously reported to be 56.7 per 10^5 persons (Lin and Dong, 2008). However, it should be noted that the estimated risk could be higher than the actual one since *Giardia* infection is only one of several factors reasons responsible for gastroenteritis.

2.3 DALY calculation for different scenarios

In the investigated region, both the conventional and advanced treatments, which have different *Giardia* removal efficiencies, were adopted for drinking water purification. The removal efficiency for the conventional treatment was 2log–2.5log, while that for advanced treatment is 4log–4.5log (Rockwell, 2003; WHO, 2009). As shown in Table 1, under the conventional treatment, the total DALYs were 0.625 per 10^5 persons (95% CI: 0.137–2.05 per 10^5 person) using Eqs. (1)–(6), which is much lower than the average DALYs for gastroenteritis diseases in China in 2004 (324 per 10^5 persons) (WHO, 2004). These findings indicate that *Giardia* infection contributes to about 0.19% (0.625/324) of gastroenteritis diseases in Zhejiang Province.

The acceptable lifetime cancer risk is 10^{-4} to 10^{-6} (Health Canada, 2004), which could be converted into a tolerable annual loss of DALYs of 1.97×10^{-7} to 1.97×10^{-5} based on a 70-year lifespan considering the average DALYs per cancer death is 13.8 years (Havelaar and Melse 2003). Thus, the health risk due to *Giardia* infection was acceptable from surface water exposure under conventional treatment in this region.

As shown in Fig. 2, the highest contribution of symptoms to total DALYs was the hospital, followed by GP. The contribution from fatalities was very low. The DALY of swimming in rivers was 0.426 with a 95% CI range of 0.031 to 1.83, showing that the exposure route of swimming contributed 79.5% to the total DALYs. It is interesting that the contribution from the route of direct consumption was only 6.1% (DALY, 0.0381; 95% CI: 2.64×10^{-3}–0.189), as shown in Table 1. As shown in Fig. 3, the health risk only decreased slightly represented by the diameter of pies when advanced treatment was used. Since the major risk contribution came from swimming in rivers, improving the water purification process could not lead

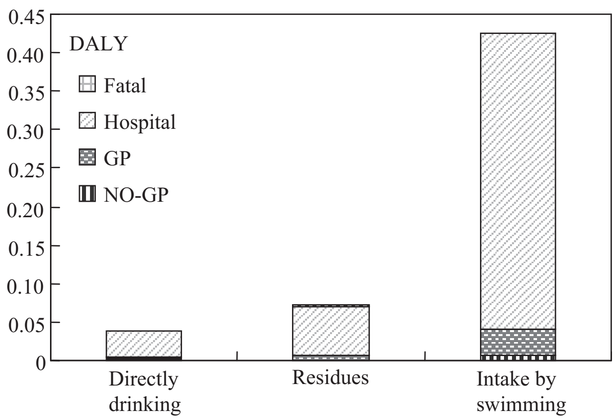

Fig. 2 DALYs for different exposure routes with different symptoms. NO-GP: no need to visit a general practitioner; GP: visited a general practitioner.

Table 1 Disability-adjusted life years (DALYs) per 10^5 persons of different routes with different treatments

Routes		Directly drinking tap water ($\times 10^{-3}$)	Intaked by residues ($\times 10^{-3}$)	Swallowed by swimming ($\times 10^{-3}$)	Sum ($\times 10^{-3}$)
Conventional treatment	NO–GP	0.565 (0.0392–2.8)	1.05 (0.0654–6.34)	5.98 (0.43–25.6)	8.91 (1.98–28.9)
	GP	3.05 (0.212–1.51)	5.72 (0.354–34.5)	35.5 (2.51–150)	50.9 (11.0–168)
	Hosp.	33.8 (2.34–167)	63.8 (3.94–386)	383 (27.6–1674)	560 (122–1840)
	Fatal	0.733 (0.0508–3.63)	0.941 (0.0658–4.72)	1.52 (0.109–6.54)	4.18 (1.19–10.6)
	Sum	38.1 (2.64–189)	71.5 (4.43–430)	426 (31–1830)	625 (137–2050)
Advanced treatment	NO-GP	0.00551 (3.66×10^{-4}–0.0309)	0.0124 (7.75×10^{-4}–0.0782)	6.03 (0.448–26)	6.06 (0.48–260)
	GP	0.0297 (1.98×10^{-3}–0.0167)	0.0676 (4.19×10^{-3}–0.426)	35.3 (2.62–152)	35.5 (2.8–152)
	Hosp.	0.329 (0.0219–1.85)	0.754 (0.0466–4.77)	386 (2.87–1670)	389 (30.7–1670)
	Fatal	7.14×10^{-3} (4.75×10^{-4}–0.04)	0.0112 (7.79×10^{-4}–0.0584)	1.53 (0.114–6.63)	1.56 (0.144–6.66)
	Sum	0.372 (0.0247–2.08)	0.845 (0.0525–5.33)	429 (32–1850)	432 (34–1850)

Results expressed as median (95% CI), where the sums are not simple the accumulation of medians in all rows or columns, but medians of summing the simulation all rows or columns using Crystal Ball software.

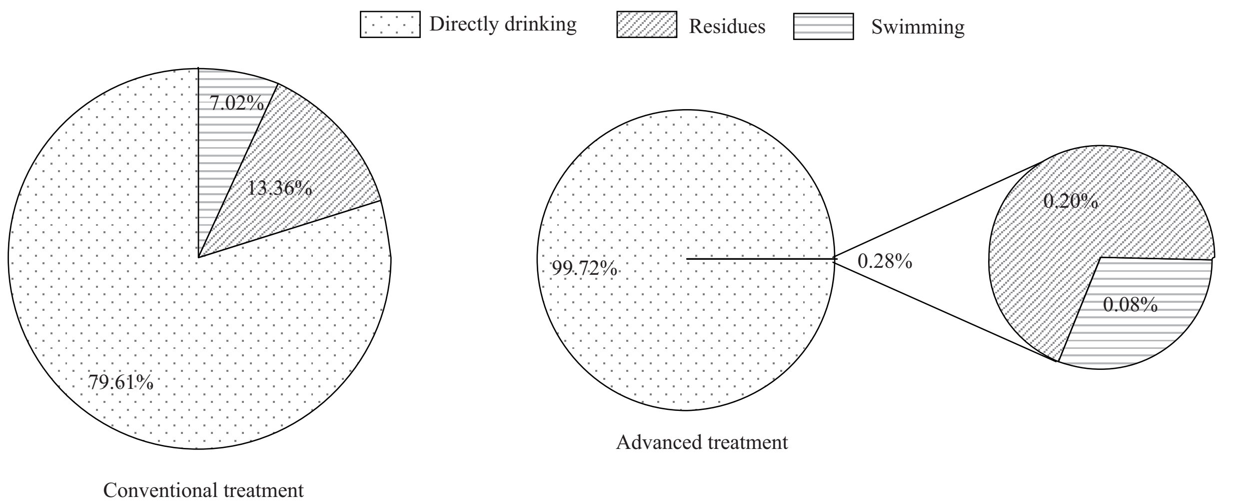

Fig. 3 Contribution to total DALYs from different exposure routes because of *Giardia* infection through conventional and advanced water treatment, respectively.

to a significant reduction of the risk caused by *Giardia* infection.

The DALY for *Giardia* from water and food in the Netherlands was 364 in a population of about 16.4 million (Vijgen et al., 2007), which was equivalent to 2.2 DALYs per 10^5 person–years, and much higher than our result (0.625 per 10^5 person–years) from the water exposure route. This was likely related to the habits of drinking boiled water and eating cooked food, because *Giardia* cysts are highly susceptible to heat (Rockwell, 2003).

3 Conclusions

The following conclusions can be drawn. The average concentration of *Giardia* oocysts in the river network area of Zhejiang Province, China was 1 cyst per 10 L, which was in accordance with most previous studies. Due to Chinese water consumption habits, the DALY for people in the region was 0.625 per 10^5 person–years, which was in the acceptable level. Swimming in rivers was the major health risk source of *Giardia* infection. This study provides a method to establish the risk of *Giardia* infection, which is useful for the modification of water quality standards based on cost–benefit analysis.

Acknowledgments

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Supporting materials

Sampling sites map and fatal-gastro probability P(f,g) associated with this article can be found in the online version.

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Supporting materials

Table S1 Parameter values of fatal-gastro probability P(f,g) at different ages (Li and Hu, 2007)

Age	$\bar{S}$ ($\times 10^4$)	P(f,g) (10^{-5})	Age	$\bar{S}$ ($\times 10^4$)	P(f,g) (10^{-5})
< 1	3808	0.83	50–54	6330	0
1–4	3090	0.15	55–59	4637	0.04
5–9	9015	0	60–64	4170	0.06
10–14	12540	0	65–69	3478	0.07
15–19	10303	0	70–74	2557	0.23
20–24	9457	0	75–79	1593	0.31
25–29	11760	0	80–84	799	0.36
30–34	12731	0.03	85–89	303	0.93
35–39	10915	0.03	90–94	78.5	0
40–44	8124	0	95–99	17.0	0
45–49	8552	0.06	100 +	1.79	0

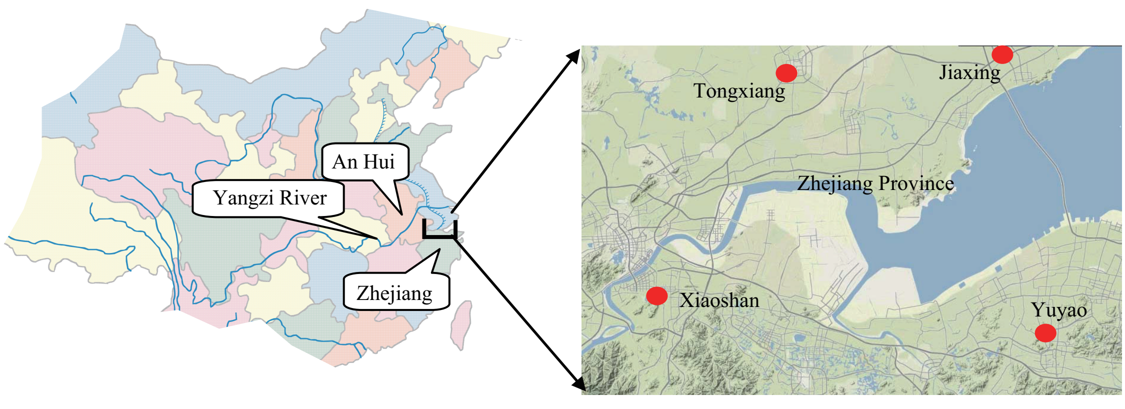

Fig. S1 Sampling sites (red cycle) of rivers that are used as sources for drinking water plants. This map was cited from reference (An et al., 2011).