Is swimming in recreational water associated with the occurrence of respiratory illness? A systematic review and meta-analysis

Alice Mannocci, Giuseppe La Torre, Alessandro Spagnoli, Angelo G. Solimini, Caterina Palazzo and Maria De Giusti

ABSTRACT

This study represents the first systematic review and meta-analysis conducted to assess the association between swimming in recreational water and the occurrence of respiratory illness. Most studies focus their attention on gastrointestinal illnesses occurring after exposure to microbial polluted water. Fourteen independent studies that included 50,117 patients with significant heterogeneity ($I^2 = 95.3\%$) were reviewed. The meta-analysis reports that people exposed to recreational water (swimmers/bathers) present a higher risk of respiratory illness compared to non-swimmers/non-bathers [relative risk (RR) = 1.63 (confidence interval at 95% [95% CI]: 1.34–1.98)]. This percentage increases if adjusted RR by age and gender [RR = 2.24 (95% CI: 1.81–2.78)] are considered. A clear association between swimming in recreational water and the occurrence of respiratory illness was found. The surveillance of water quality monitoring systems is crucial not only for gastrointestinal illness, but also for respiratory ones.

Key words | meta-analysis, recreational water, respiratory illness, swimming, systematic review, water quality

Alice Mannocci (corresponding author)
Giuseppe La Torre
Alessandro Spagnoli
Angelo G. Solimini
Caterina Palazzo
Maria De Giusti
Department of Public Health and Infectious Diseases,
Sapienza University of Rome,
Piazzale Aldo Moro 5,
Rome 00185,
Italy
E-mail: *alice.mannocci@uniroma1.it*

Maria De Giusti
Giuseppe La Torre
Accademia Romana di Sanità Pubblica,
Via Giovanni Nicotera 29,
Rome 00195,
Italy

INTRODUCTION

A number of scientific studies outline the complicated issue of illnesses associated with bathing in polluted water (Prüss 1998; Prüss *et al.* 2002; Doménech-Sánchez *et al.* 2008; Hlavsa *et al.* 2015). Some of the consequences of these waterborne infections can be serious and life-threatening in vulnerable people such as children, the elderly, pregnant women and immunosuppressed subjects (Alexander *et al.* 1992; Frisby *et al.* 1997; Wade *et al.* 2003).

Often studies analyze the gastrointestinal consequences resulting from exposure to and ingestion of microorganisms that live in wastewater in which many people bathe every year (Cabelli *et al.* 1982; Wade *et al.* 2008; Soller *et al.* 2010; Sanborn & Takaro 2013). On the contrary, little is known about the respiratory effects of such exposure. These respiratory effects may be noticed both at upper and lower levels of the airways (Bougault *et al.* 2009).

In fact, when the bather is immersed in recreational water, he/she is potentially exposed to pathogens, toxins and irritants that could have an impact on their health state (Abdelzaher *et al.* 2011). In particular, accidental ingestion of recreational water contaminated by fecal and enteric viruses and bacterial contamination can often cause the onset of gastrointestinal illnesses, as well as respiratory diseases, and those affecting the eye, ear and skin (Griffin *et al.* 2001; Praveena *et al.* 2013, 2015). In this regard, most studies report a dose-related increase of health risk in bathers with an increase in the bacterial concentration in recreational waters (Kamizoulis & Saliba 2004; Kay *et al.* 2004; Lévesque & Gauvin 2007; Yoder *et al.* 2008; Almeida *et al.* 2012). Relative risk (RR) values for swimmers in polluted water versus clean water often indicate this exposure as a risk factor (usually $1.0 < RR < 3.0$) (Prüss 1998). Therefore, the form of recreational activity plays a

doi: 10.2166/wh.2016.266

significant role. Routes of exposure can be direct surface contact with skin, eyes and mucous membranes, as well as through inhalation and ingestion.

Moreover, the occurrence of diseases also depends on the period and the type of exposure, together with the immune status of the person. So many studies have shown that people with immunodeficiency are more susceptible to waterborne infections, and tend to suffer more severe outcomes (Pond 2005).

In addition, it is important to underline that in persons living in coastal areas the risk of this kind of disease is doubled compared to citizens in the rest of the world (Henrickson *et al.* 2001).

It has been estimated that every year more than 50 million cases of severe respiratory diseases are the result of swimming in recreational polluted water. The annual number of cases of acute respiratory infections associated with swimming/bathing in polluted seawater is equal to 48,125,000 cases per year, whilst infections of the lower respiratory tract amount to 1,636,250 cases (Shuval 2003).

It is evident, therefore, that institutions need to understand the importance of this condition, which concerns people worldwide. They must aim to prevent waterborne illnesses and to activate and maintain efficient surveillance systems like proper water quality monitoring, sanitary surveys, animal waste control measures, wastewater treatment, risk communication and information dissemination to increase public awareness (Pond 2005).

There is evidence that the prevalence of upper airway respiratory illnesses like rhinitis, sinusitis, rhinopathy (disease of the nose) and airway hyper-responsiveness is increased in 'bathers/swimmers' compared to the general population, but no general overview has been conducted, until now. With that, the aim of the present study is to systematically review and meta-analyze the association between swimming in recreational water and the occurrence of respiratory illness.

MATERIALS AND METHODS

Literature search and study inclusion criteria

The systematic review and meta-analysis were performed according to PRISMA (Liberati *et al.* 2009). (See Appendix for PRISMA checklist, available with the online version of this paper.) Online bibliographic databases were searched up to February 2015. Two researchers independently looked at PubMed and Scopus databases.

The keywords used were: 'recreational water' AND 'health effects' AND 'respiratory illness' AND 'epidemiol*'.

The selection was limited to articles published in English, Italian, French and Spanish, and no study design restriction was applied.

The search was further refined by examining the bibliography of the selected articles in order to find further studies of potential interest.

The articles were examined and excluded if:

1. they researched professional swimmers;
2. studies were not pertaining to respiratory disease.

This led to a strict selection of the results.

When PubMed and Scopus outcomes overlapped, all duplicate articles were removed. For eligible papers, the full text was then obtained.

The data extracted from the full text were synthesized in the first row of Table 1. In particular these were: qualitative characteristics (name of the first author, country, year of publication), sample size of the population involved, type of water (marine/fresh), outcomes (symptoms studied), water pollution (contaminated/uncontaminated), incidence rate, RR, adjusted RR (adjRR) by age and gender and quality assessment.

Methodological quality assessment

The quality of the observational studies included was assessed by one author (A.S.) using the modified Newcastle-Ottawa Scale (Stang 2010). The low quality was ranged <7 points out of 8.

The methodological quality of the only randomized clinical trial retrieved was assessed by the Jadad scale (Egger *et al.* 1997).

Statistical analysis

The meta-analyses were conducted using the statistical software StatsDirect 3.0 and Episheet, for the pooled analysis of unadjusted and adjRRs, respectively. Forest plots were charted to illustrate the results of individual studies and meta-analyses. The Cochran Q test was used to estimate

Table 1 | Characteristics of the cohort studies included in the meta-analysis

Author	Publication year	Country	Respiratory illness: symptom	Recreational water	Polluted	Subjects enrolled	I.R. Exposes	I.R. Non-exposes	Crude RR	AdjRR[a] (95% CI)	Quality score[b]
V.J. Cabelli	1979	USA	Sore throat; bad cough; chest cold; runny or stuffed nose	Marine	Barely acceptable vs uncontaminated	10,069	0.049	0.313	0.158	NA	7
P.L. Seyfried	1985	Canada	Sore throat; cold or cough; runny or stuffed nose; sneezing	Lakes	Uncontaminated[c]	4,537	0.152	0.064	2.366	NA	7
L.M. Alexander	1992	UK	Runny nose; blocked nose; sore throat; dry cough; cough with phlegm; breathing difficulties	Marine	Contaminated	1,600	0.490	0.467	1.048	NA	8
Y.E.R. Von Schirithing	1992	USA	Sore throat; cough; cold; runny/stuffy nose wheezing; tight chest	Marine	Contaminated	733	0.054	0.047	1.151	NA	5
S.J. Corbett	1993	Australia	Cough, cold, fever, or symptoms suggestive of flu	Marine	Contaminated vs uncontaminated	2,839	0.765	0.440	1.736	1.9 (1.4–2.4)	7
J.M. Fleisher	1996	UK	Sore throat and/or runny nose and/or dry or productive cough	Marine	Contaminated	1,216	0.049	0.030	1.646	2.65 (1.19–5.48)	7
G.B. McBride	1998	New Zealand	Dry cough; cough with spit; shortness of breath; chest pain with fever	Marine	Contaminated and uncontaminated	3,507	0.039	0.023	1.738	3.92 (1.59–9.49)	7
I.A. van Asperen	1998	UK	Respiratory tract (not specified)	Fresh	Contaminated	1,600	0.111	0.045	2.457	NA	5
M.D. Prieto	2001	Spain	Upper respiratory tract (not specified)	Marine	Contaminated	1,858	0.026	0.018	1.394	NA	6
I. Stewart	2006	Australia USA	Difficulty breathing; dry cough; productive cough; runny nose; unusual sneezing; sore throat; wheezy breathing	Fresh (lakes and rivers)	Contaminated and uncontaminated	1,331	0.034	0.029	1.167	NA	6
J.M. Colford	2007	USA	cough, cough with phlegm, nasal congestion or runny nose, sore throat, and significant respiratory disease, defined as: fever plus nasal congestion; or fever plus sore throat; or cough with phlegm	Marine	Contaminated and uncontaminated	8,797	0.428	0.347	1.232	2.91 (1.77–4.77)	7

(*continued*)

Table 1 | continued

Author	Publication year	Country	Respiratory illness: symptom	Recreational water	Polluted	Subjects enrolled	I.R. Exposes	I.R. Non-exposes	Crude RR	AdjRR[a] (95% CI)	Quality score[b]
T.J. Wade	2010	USA	Sore throat, cough, runny nose, cold, or fever	Marine	Contaminated	6,350	0.083	0.047	1.764	1.78 (1.02–3.11)	6
P. Papastergiou	2012	Greece	Sore throat, dysphagia, rheum (runny nose), cough, hoarseness	Marine	Uncontaminated	4,377	0.589	0.192	3.064	4.28 (1.35–13.51)	7

I.R., incidence rate; NA, not available.
[a]Adjusted RR by age and gender.
[b]Range of quality according to Newcastle scale: max = 8, min = 0.
[c]*Source:* Seyfried *et al.* (1985b).

heterogeneity followed by calculation of I^2 (percentage of effect size attributable to heterogeneity). Effect size heterogeneity was considered significant for values $p < 0.10$ or $I^2 > 0.20$. The pooled RR and relative Confidence Interval at 95% (95% CI) was computed.

Publication bias was quantified by inspection of funnel plots and computation of Egger and Begg's test probability values (Sutton 2000) where $p < 0.05$ most likely reflects publication bias.

Results from multivariate regression analyses in individual studies were meta-analyzed using a conservative inverse variance based random effects pooling method (DerSimonian & Laird 1986).

Moreover, two meta-regression analyses were conducted using multiple linear regression models, with the RR as the dependent variable (adjusted and not adjusted by gender and age), and the following ones as covariates: Newcastle-Ottawa score, year of publication over 1996 (median), total number of people in the cohort study, continent of the study (America vs other countries). This analysis was conducted using SPSS 21.

The significance level of all statistical evaluations was set at $p < 0.05$.

RESULTS

Characteristics of retrieved studies

In the flowchart (Figure 1) 134 articles were retrieved from the electronic literature by PubMed and Scopus, and 50 from the bibliographies of published literature. After title and abstract screening, we found and excluded 53 duplicates and 104 articles that did not investigate the association between recreational water and respiratory illness. Of these, the researchers (A.S. and A.M.) independently reviewed 27 full-text articles for eligibility and retained 14 articles for the quantitative data synthesis. These were 13 cohort studies (Cabelli *et al.* 1979; Seyfried *et al.* 1985a; Alexander *et al.* 1992; von Schirnding *et al.* 1992; Corbett *et al.* 1993; Fleisher *et al.* 1996; Mcbride *et al.* 1998; van Asperen *et al.* 1998; Prieto 2001; Stewart *et al.* 2006; Colford *et al.* 2007; Wade *et al.* 2010; Papastergiou *et al.* 2012) and one randomized clinical trial (RCT) (Fleisher *et al.* 2010).

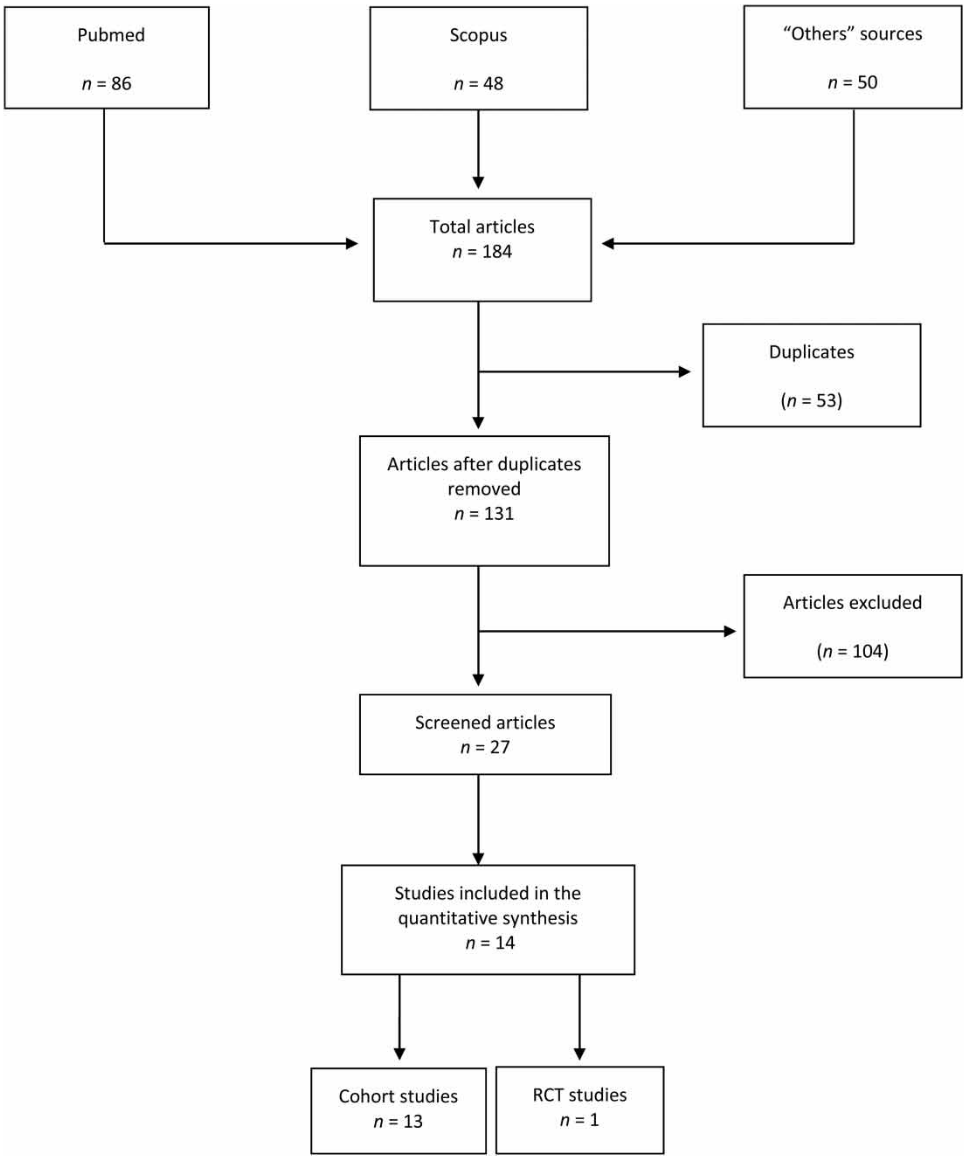


Figure 1 | Flow-chart of the selection of the scientific articles.

Meta-analysis of the cohort studies

In Table 1, the information and useful data from all cohort studies are summarized. The studies were published between 1979 and 2012 and five of these were in Europe. A total of 23,728 swimmers and 22,803 non-swimmers were included in the meta-analysis. Figure 2 presents the forest-plot of all cohort studies.

The random effect model was applied to compute the combined RR according to the heterogeneity found, and this is referred as Cochran $Q = 253.12$ with $p < 0.001$; $I^2 = 95.3\%$ (95% CI: 93.8–96.2%).

The risk of having symptoms or respiratory illness was significantly higher in swimmers/bathers than in non-swimmers/non-bathers [RR = 1.63; 95% CI: 1.34–1.98]. The funnel plot in Figure 3 reflects an absence of publication bias according to the probability values resulting from the Egger ($p = 0.178$) and Begg ($p = 0.590$) tests.

In Figure 4, six studies that reported explicit RRs adjusted by gender and age were included. A significantly higher RR in

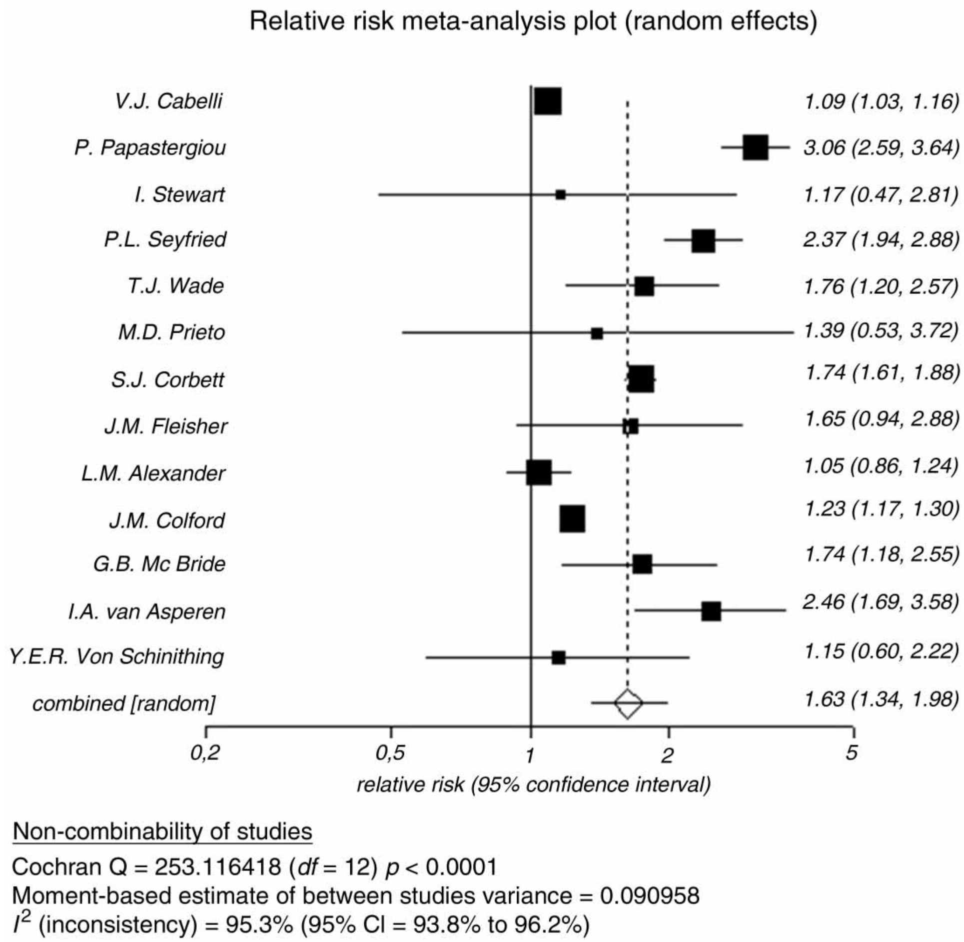


Figure 2 | Forest-plot of all included studies (random effects model).

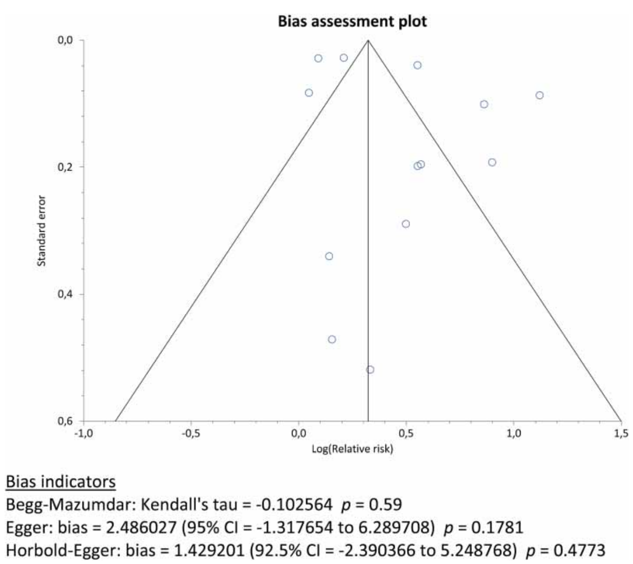
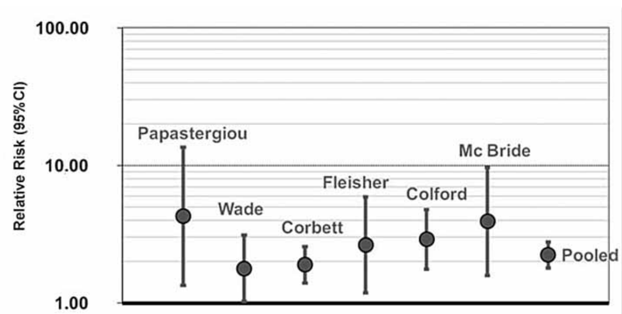


Figure 3 | Funnel plot of all included studies.



Study	RR	95% CI		Relative weight
		Lower	Upp	
P. Papastergiou	4.280	1.350	13.51	0.03
T.J. Wade	1.780	1.020	3.11	0.15
S.J. Corbett	1.900	1.400	2.40	0.50
J.M.Fleisher	2.650	1.190	5.48	0.07
J.M. Colford	2.910	1.770	4.77	0.19
G.B. Mc Bride	3.920	1.590	9.49	0.06
Pooled	**2.239**	**1.805**	**2.777**	**1.00**

p for homogeneity test :	**0.337**

Figure 4 | Forest-plot of studies with adjusted RR available (fixed effects model).

comparison to all studies included in the meta-analysis was found (RR = 2.24; 95% CI: 1.81–2.78).

The first meta-regression (Table 2) model that considers RR outcomes gave no significant associations; on the other hand, the second model, which considers the adjRR (Table 3), shows a significantly decreased risk in studies published in America (beta = −1.93; $p = 0.001$), and a low quality Newcastle-Ottawa score (beta = −0.103; $p = 0.015$). Significant direct associations with the risk of symptoms were found in articles published from 1996 (beta = 0.571; $p = 0.002$) and articles with increased sample size (beta = 1.501; $p = 0.002$).

Quality of the cohort studies

One cohort study obtained the maximum score of 8. The median quality was 7 out of 8. The minimum and maximum values were 5 and 8, respectively. A total of 61% of the studies ($n = 8$) had high quality: >6 points.

Figure 5 shows the distribution of the 13 observational studies included in the meta-analysis according to the Newcastle-Ottawa quality scale's criteria. All studies met the following Newcastle-Ottawa items: representativeness of the exposed cohort; selection of the non-exposed cohort; ascertainment of exposure; demonstration that outcome of interest was not present at the start of the study; was follow-up long enough for outcomes to occur.

On the other hand, the item which was less confirmed was the unbiased 'assessment of outcome' ($n = 1$); in the majority of studies ($n = 12$) the assessment of the outcome was self-reported.

Table 2 | Meta-regression of all cohort studies

	Beta	p
(Constant)		0.300
NEWCASTLE	−0.127	0.768
Year over 1996	0.128	0.748
America	−0.445	0.326
People in the cohort	0.244	0.595

Dependent variable: RR.

Table 3 | Meta-regression of cohort studies with multivariate analysis

	Beta	p
(Constant)	1.632	0.011
Newcastle-Ottawa score	−0.192	0.015
Year over 1996	1.428	0.002
America	−3.812	0.001
People in the cohort	0.001	0.002

Dependent variable: adjusted RR.

Description of the RCT study

The RCT was conducted in subtropical recreational marine waters (Fleisher *et al.* 2010) and shows that swimmers/bathers have an increased risk of several illnesses in comparison with non-swimmers/non-bathers, even in the absence of any known source of domestic sewage impacting on subtropical recreational marine waters. The study enrolled a total of 1,303 people, separated into swimmers/bathers and non-swimmers/non-bathers. Findings indicated that swimmers/bathers were 4.46 times more likely to report acute febrile respiratory illness (95% CI: 0.99–20.90).

DISCUSSION

Every year throughout the world, there are more than 50 million cases of severe respiratory diseases (of which 1,636,250 are infections of the lower respiratory tract) attributable to swimming in recreational polluted water (Shuval 2003). While the relationship between the ingestion of recreational water containing fecal bacteria and gastrointestinal symptoms/infections has been known and well established in medicine, the relationship with respiratory infections is not as clear.

The observed association between swimming in recreational waters and the occurrence of respiratory illness might not necessarily be because of whole body immersion either. However, there is the possibility that increased illnesses among bathers can be caused by bather to bather transmission via water (gastrointestinal illness) and air (respiratory pathogens). Respiratory symptoms among bathers are not always symptoms of respiratory infections, and therefore might occur because of exposure to non-microbiological agents (e.g. chemicals) or due to factors related to bather homeostasis. In addition, respiratory infections might occur

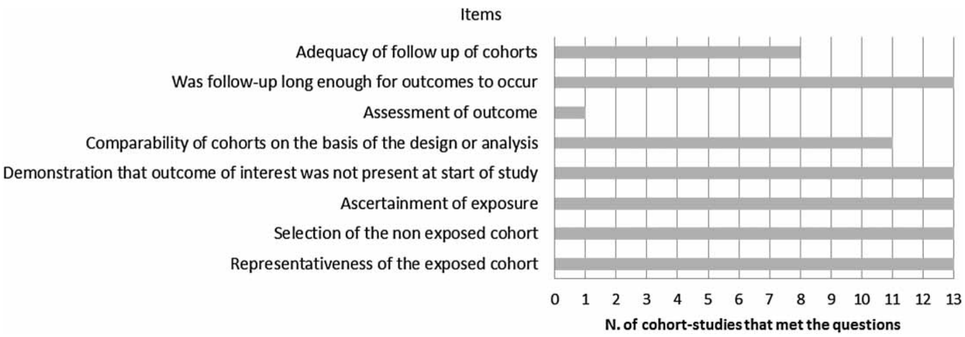


Figure 5 | Distribution of the 13 cohort studies on the Newcastle-Ottawa quality assessment scale's items.

because of close contact with other bathers and therefore depend on the crowded condition (the bather density) of a beach (Abdelzaher *et al.* 2011; Praveena *et al.* 2015).

The case study presented here was conducted to demonstrate the association between swimming in recreational water and the occurrence of respiratory illness. This is the first systematic review and meta-analysis specific to this argument. In fact, most studies focus their attention on the gastrointestinal illnesses that appear after exposure to microbial-pollution water.

Results support the hypothesis that people exposed to recreational water, identified as 'swimmers/bathers', present a higher risk of symptoms or respiratory illness, equal to 63%, compared to 'non-swimmers/non-bathers' (Figure 2). This percentage increases if we consider the adjRR by age and gender (RR = 2.24) (Figure 4). A possible explanation for this may be that gender and age could be confounders and/or effect modifiers of the risk of respiratory illness. The possible reason for this is probably due to the fact that males and females have different levels of activity in the recreational water, and that age is associated with a higher level of the mobility that may increase exposure to pathogens in the bathing environment.

This finding shows that, where people immerse their body in recreational water, not only do gastrointestinal diseases occur, but also respiratory infections, even if a dose-related relationship between respiratory illness and water quality measured by bacterial indicator counts exists. In this sense, institutions of the countries where the water sanitary inspection may be lower have to understand the importance of this risk, and implement efficient surveillance systems including water quality inspection and analysis, monitoring, sanitary surveys, animal waste control measures, wastewater treatment and risk communication and information dissemination. According to the World Health Organization (WHO) the first aim is 'obtain the most rigorous and relevant evidence regarding water quality and health' in order to provide up-to-date, harmonized water quality management guidelines and supporting resources (WHO 2013).

Points of weakness

There are some limitations to this study, primarily inherent to the significant heterogeneity observed. This could be due to a variety of factors. There aren't solid homogeneities regarding the classification of exposure and the evaluation of effects. Some studies describe the exposure through the total/not-total immersion of the body, whereas others describe exposure through the immersion or non-immersion of the head. There were also different durations of swimming/exposure. However, the use of a random effect model allows us to consider the higher variability between studies. A source of bias could be that the authors' definitions of respiratory illness (outcomes) may not be entirely similar: globally, the definition is similar but not the same, and in two articles the symptoms considered were not explained clearly.

Finally, possible effects may depend on different quality (contaminated and not) and types (fresh/marine) of water: the majority of studies investigated bathing in polluted and marine/coastal waters.

Points of strength

The strengths of this review include a comprehensive search for relevant studies, the systematic and unambiguous application of eligibility criteria, the cautious consideration of study quality, and a rigorous analysis. The acceptable quality of the studies analyzed (median = 7 and 61% of the studies obtained > 6 score quality) could be a robust support to the evidence found. In particular, the items concerning the selection of the sample (such as ascertainment of exposure and the truly representative nature of the community) and adequate length of follow-up were satisfactory in all studies.

CONCLUSIONS

This study shows a clear association between swimming in recreational water and the occurrence of respiratory illness. People exposed to recreational water ('swimmers/bathers') present a higher risk (increased by 63–124%) of having symptoms or respiratory illness compared to those not exposed ('non-swimmers/non-bathers').

REFERENCES

Abdelzaher, A. M., Wright, M. E., Ortega, C., Hasan, A. R., Shibata, T., Solo-Gabriele, H. M., Kish, J., Withum, K., He, G., Elmir, S. M., Bonilla, J. A., Bonilla, T. D., Palmer, C. J., Scott, T. M., Lukasik, J., Harwood, V. J., McQuaig, S., Sinigalliano, C. D., Gidley, M. L., Wanless, D., Plano, L. R. W., Garza, A. C., Zhu, X., Stewart, J. R., Dickerson, J. W., Yampara-Iquise, H., Carson, C., Fleisher, J. M. & Fleming, L. E. 2011 Daily measures of microbes and human health at a non-point source marine beach. *J. Water Health* **9**, 443–457.

Alexander, L. M., Heaven, A., Tennant, A. & Morris, R. 1992 Symptomatology of children in contact with sea water contaminated with sewage. *J. Epidemiol. Community Health* **46**, 340–344.

Almeida, C., González, S. O., Mallea, M. & González, P. 2012 A recreational water quality index using chemical, physical and microbiological parameters. *Environ. Sci. Pollut. Res. Int.* **19**, 3400–3411.

Bougault, V., Turmel, J., Levesque, B. & Boulet, L. P. 2009 The respiratory health of swimmers. *Sports Med. Auckl. NZ* **39**, 295–312.

Cabelli, V. J., Dufour, A. P., Levin, M. A., McCabe, L. J. & Haberman, P. W. 1979 Relationship of microbial indicators to health effects at marine bathing beaches. *Am. J. Public Health* **69**, 690–696.

Cabelli, V. J., Dufour, A. P., McCabe, L. J. & Levin, M. A. 1982 Swimming-associated gastroenteritis and water quality. *Am. J. Epidemiol.* **115**, 606–616.

Colford, J. M., Wade, T. J., Schiff, K. C., Wright, C. C., Griffith, J. F., Sandhu, S. K., Burns, S., Sobsey, M., Lovelace, G. & Weisberg, S. B. 2007 Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination. *Epidemiol. Camb. Mass.* **18**, 27–35.

Corbett, S. J., Rubin, G. L., Curry, G. K. & Kleinbaum, D. G. 1993 The health effects of swimming at Sydney beaches. The Sydney Beach Users Study Advisory Group. *Am. J. Public Health* **83**, 1701–1706.

DerSimonian, R. & Laird, N. 1986 Meta-analysis in clinical trials. *Control. Clin. Trials* **7**, 177–188.

Doménech-Sánchez, A., Olea, F. & Berrocal, C. I. 2008 Infections related to recreational waters. *Enferm. Infecc. Microbiol. Clin.* **26**, 32–37.

Egger, M., Davey Smith, G., Schneider, M. & Minder, C. 1997 Bias in meta-analysis detected by a simple, graphical test. *BMJ* **315**, 629–634.

Fleisher, J. M., Kay, D., Salmon, R. L., Jones, F., Wyer, M. D. & Godfree, A. F. 1996 Marine waters contaminated with domestic sewage: nonenteric illnesses associated with bather exposure in the United Kingdom. *Am. J. Public Health* **86**, 1228–1234.

Fleisher, J. M., Fleming, L. E., Solo-Gabriele, H. M., Kish, J. K., Sinigalliano, C. D., Plano, L., Elmir, S. M., Wang, J. D., Withum, K., Shibata, T., Gidley, M. L., Abdelzaher, A., He, G., Ortega, C., Zhu, X., Wright, M., Hollenbeck, J. & Backer, L. C. 2010 The BEACHES study: health effects and exposures from non-point source microbial contaminants in subtropical recreational marine waters. *Int. J. Epidemiol.* **39**, 1291–1298.

Frisby, H. R., Addiss, D. G., Reiser, W. J., Hancock, B., Vergeront, J. M., Hoxie, N. J. & Davis, J. P. 1997 Clinical and epidemiologic features of a massive waterborne outbreak of cryptosporidiosis in persons with HIV infection. *J. Acquir. Immune Defic. Syndr. Hum. Retrovirol.* **16**, 367–373.

Griffin, D. W., Lipp, E. K., McLaughlin, M. R. & Rose, J. B. 2001 Marine recreation and public health microbiology: quest for the ideal indicator. *BioScience* **51**, 817–825.

Henrickson, S. E., Wong, T., Allen, P., Ford, T. & Epstein, P. R. 2001 Marine swimming-related illness: implications for monitoring and environmental policy. *Environ. Health Perspect.* **109**, 645–650.

Hlavsa, M. C., Roberts, V. A., Kahler, A. M., Hilborn, E. D., Mecher, T. R., Beach, M. J., Wade, T. J. & Yoder, J. S. 2015 Outbreaks of illness associated with recreational water – United States, 2011-2012. *MMWR Morb. Mortal. Wkly. Rep.* **64**, 668–672.

Kamizoulis, G. & Saliba, L. 2004 Development of coastal recreational water quality standards in the Mediterranean. *Environ. Int.* **30**, 841–854.

Kay, D., Bartram, J., Prüss, A., Ashbolt, N., Wyer, M. D., Fleisher, J. M., Fewtrell, L., Rogers, A. & Rees, G. 2004 Derivation of numerical values for the World Health Organization guidelines for recreational waters. *Water Res.* **38**, 1296–1304.

Lévesque, B. & Gauvin, D. 2007 Microbiological guideline values for recreational bathing in Canada: time for change? *Can. J. Infect. Dis. Med. Microbiol.* **18**, 153–157.

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J. & Moher, D. 2009 The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med.* **6**, e1000100.

Mcbride, G. B., Salmond, C. E., Bandaranayake, D. R., Turner, S. J., Lewis, G. D. & Till, D. G. 1998 Health effects of marine bathing in New Zealand. *Int. J. Environ. Health Res.* **8**, 173–189.

Papastergiou, P., Mouchtouri, V., Pinaka, O., Katsiaflaka, A., Rachiotis, G. & Hadjichristodoulou, C. 2012 Elevated bathing-associated disease risks despite certified water quality: a cohort study. *Int. J. Environ. Res. Public. Health* **9**, 1548–1565.

Pond, K. 2005 *Water Recreation and Disease: Plausibility of Associated Infections: Acute Effects, Sequelae and Mortality, Emerging Issues in Water and Infectious Disease Series*. IWA Publishing, London.

Praveena, S. M., Chen, K. S. & Ismail, S. N. S. 2013 Indicators of microbial beach water quality: preliminary findings from Teluk Kemang beach, Port Dickson (Malaysia). *Mar. Pollut. Bull.* **76**, 417–419.

Praveena, S. M., Pauzi, N. M., Hamdan, M. & Sham, S. M. 2015 Assessment of swimming associated health effects in marine bathing beach: an example from Morib beach (Malaysia). *Mar. Pollut. Bull.* **92**, 222–226.

Prieto, M. D. 2001 Recreation in coastal waters: health risks associated with bathing in sea water. *J. Epidemiol. Community Health* **55**, 442–447.

Prüss, A. 1998 Review of epidemiological studies on health effects from exposure to recreational water. *Int. J. Epidemiol.* **27**, 1–9.

Prüss, A., Kay, D., Fewtrell, L. & Bartram, J. 2002 Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environ. Health Perspect.* **110**, 537–542.

Sanborn, M. & Takaro, T. 2013 Recreational water-related illness: office management and prevention. *Can. Fam. Physician Médecin Fam. Can.* **59**, 491–495.

Seyfried, P. L., Tobin, R. S., Brown, N. E. & Ness, P. F. 1985a A prospective study of swimming-related illness. I. Swimming-associated health risk. *Am. J. Public Health* **75**, 1068–1070.

Seyfried, P. L., Tobin, R. S., Brown, N. E. & Ness, P. F. 1985b A prospective study of swimming related illness. II. Morbidity and the microbiological quality of water. *Am. J. Public Health* **75**, 1071–1075.

Shuval, H. 2003 Estimating the global burden of thalassogenic diseases: human infectious diseases caused by wastewater pollution of the marine environment. *J. Water Health* **1**, 53–64.

Soller, J. A., Bartrand, T., Ashbolt, N. J., Ravenscroft, J. & Wade, T. J. 2010 Estimating the primary etiologic agents in recreational freshwaters impacted by human sources of faecal contamination. *Water Res.* **44**, 4736–4747.

Stang, A. 2010 Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur. J. Epidemiol.* **25**, 603–605.

Stewart, I., Webb, P. M., Schluter, P. J., Fleming, L. E., Burns, J. W., Gantar, M., Backer, L. C. & Shaw, G. R. 2006 Epidemiology of recreational exposure to freshwater cyanobacteria–an international prospective cohort study. *BMC Public Health* **6**, 93.

Sutton, A. J. (ed.) 2000 *Methods for Meta-Analysis in Medical Research*. Wiley series in probability and statistics. Wiley, Chichester.

van Asperen, I. A., Medema, G., Borgdorff, M. W., Sprenger, M. J. & Havelaar, A. H. 1998 Risk of gastroenteritis among triathletes in relation to faecal pollution of fresh waters. *Int. J. Epidemiol.* **27**, 309–315.

von Schirnding, Y. E., Kfir, R., Cabelli, V., Franklin, L. & Joubert, G. 1992 Morbidity among bathers exposed to polluted seawater. A prospective epidemiological study. *South Afr. Med. J. Suid-Afr. Tydskr. Vir Geneeskd.* **81**, 543–546.

Wade, T. J., Pai, N., Eisenberg, J. N. S. & Colford, J. M. 2003 Do U.S. Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. *Environ. Health Perspect.* **111**, 1102–1109.

Wade, T. J., Calderon, R. L., Brenner, K. P., Sams, E., Beach, M., Haugland, R., Wymer, L. & Dufour, A. P. 2008 High sensitivity of children to swimming-associated gastrointestinal illness: results using a rapid assay of recreational water quality. *Epidemiol. Camb. Mass.* **19**, 375–383.

Wade, T. J., Sams, E., Brenner, K. P., Haugland, R., Chern, E., Beach, M., Wymer, L., Rankin, C. C., Love, D., Li, Q., Noble, R. & Dufour, A. P. 2010 Rapidly measured indicators of recreational water quality and swimming-associated illness at marine beaches: a prospective cohort study. *Environ. Health Glob. Access Sci. Source* **9**, 66.

WHO 2013 *Water Quality and Health Strategy 2013–2020*. World Health Organization. http://www.who.int/water_sanitation_health/publications/2013/water_quality_strategy/en/ (accessed 12 January 2016)

Yoder, J., Roberts, V., Craun, G. F., Hill, V., Hicks, L. A., Alexander, N. T., Radke, V., Calderon, R. L., Hlavsa, M. C., Beach, M. J. & Roy, S. L. 2008 Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking – United States, 2005-2006. *MMWR Surveill. Summ. CDC* **57**, 39–62.

First received 30 October 2015; accepted in revised form 14 January 2016. Available online 18 February 2016