© International Epidemiological Association 1998 Printed in Great Britain International Journal of Epidemiology 1998;27 1–9

Review of epidemiological studies on health effects from exposure to recreational water

Annette Prüss

Background In order to facilitate the setting of guidelines, this review article evaluates the health risks caused by poor microbiological quality of recreational natural water.

Methods Studies on uncontrolled waters, such as sea, lakes and rivers were considered in this review through MEDLINE and WHO resources. Out of the 37 studies identified, 22 were reviewed because they addressed associations of interest and fulfilled the validity criteria.

Results Most studies reported a dose-related increase of health risk in swimmers with an increase in the indicator-bacteria count in recreational waters. Relative risk (RR) values for swimming in polluted water versus clean water were often significant (usually $1.0 < RR < 3.0$). The indicator microorganisms that correlate best with health outcomes were enterococci/faecal streptococci for both marine and freshwater, and *Escherichia coli* for freshwater. In both marine and freshwater, increased risk of gastro-intestinal symptoms was reported for water quality values ranging from only a few indicator counts/100 ml to about 30 indicator counts/100 ml. These values are low compared with the water qualities frequently encountered in coastal recreational waters. Studies which showed a higher threshold for increased risk and case-rate values in some countries may suggest immunity due to endemicity or a lower pathogen-to-indicator ratio in the natural waters.

Conclusions The review strongly suggests a causal dose-related relationship between gastro-intestinal symptoms and recreational water quality measured by bacterial indicator counts.

Keywords Bathing water, water quality, WHO Guidelines, swimming, swimming-associated illness, indicator organisms

Accepted 23 June 1997

Numerous epidemics and cases related to swimming in recreational waters have long been reported. The World Health Organization (WHO), as the international public health authority, has been requested repeatedly to issue authoritative guidelines on the quality of recreational waters for national health authorities as well as the general public, which would affect tourism and the management of beach resorts worldwide. This review has, therefore, been carried out in the framework of the WHO project for setting guidelines for the quality of recreational water and bathing beaches. It is designed to provide a scientific basis for the derivation of guideline values for the microbiological quality of uncontrolled waters (natural water bodies such as lakes, rivers or the sea).

World Health Organization, Urban Environmental Health, Division of Operational Support in Environmental Health, 1211 Geneva, Switzerland.

Selection of studies

Since the 1950s, epidemiological studies have investigated the relationship between health risk and swimming. These epidemiological studies have investigated mainly gastro-intestinal symptoms, eye infections, skin complaints, ear, nose and throat infections and respiratory illness. They concluded that the rates of several symptoms were increased in swimmers compared with non-swimmers. Outbreak reports confirm causative relations between certain outcomes and swimming. Relevant studies from the existing literature were selected with a view to evaluating the following relationships: (1) the dose-response relationship between health outcomes and bathing water quality; (2) the existence of threshold values of indicator-bacteria counts for health outcomes; and (3) a possible variation in the severity of outcomes as a function of microbiological water quality.

Recent studies have suggested that certain symptoms may result from exposure to water itself rather than from microbiological water quality,[1] for example, by irritation or disturbance of the body's defences. Also, bather and non-bather groups may differ (e.g. in their health status), which may be the cause of the choice of different activities (i.e. bathing or not bathing). Furthermore, non-swimmers may also be exposed to poor water quality, since viruses may be transferred from the water to the air.[2] Thus, swimming-associated illness estimation using non-swimmers on the beach as the unexposed groups may underestimate the true effect.

To estimate each risk factor independently, the following associations were studied in this review: (1) the incidence rates for swimming in relatively unpolluted water compared with the incidence rates of non-swimmers, to assess the risk of contact with water itself; and (2) the incidence rates for swimming in polluted water compared with the incidence rates of swimmers in relatively unpolluted water, to assess risk due to microbiological water quality.

To address the associations of interest, studies that met the following criteria were excluded: (1) The health outcomes are not clearly related to water quality. (2) The study only compares attack rates of swimmers in polluted water to attack rates of non-swimmers, and the associations of interest could not be calculated from the reported data. (3) The exposure or outcome assessment differs significantly among the exposure or outcome groups. (4) The study is not sufficiently documented for determining the associations of interest. (5) The study population is far too small (three or less diseased per exposure groups). (6) The response rate is low (less than 50%). (7) The water of exposure is artificially chlorinated.

In this review, 22[3–24] of 36[3–38] studies were selected (Table 1).

Of the 22 studies, 18 are prospective cohort studies, two are retrospective cohort studies[16,23] and only two[3,9] are randomized controlled trials. Prospective cohort studies are suitable for studying the associations of interest; they may however have two major limitations: variation of the composition in different exposure groups, and loss of follow-up in populations such as tourists. In retrospective cohort studies, estimation of exposure to water quality may be inaccurate. Randomized controlled trials permit more accurate assignment of exposure to water and its quality assessment, and optimize the chance of similarity between the groups of exposure. However, they present ethical problems (e.g. exposing subjects to water of low quality or inclusion of children) and practical problems (e.g. cost, recruitment of sufficient number of participants).

All studies assessed water quality by measuring indicator microorganisms, usually bacteria of faecal origin. The studies used different indicators, the most commonly used being enterococci, *Escherichia coli* and faecal coliforms. Only a few studies also measured pathogenic microorganisms.

In 11 of the selected studies,[3,4,6,7,9,12,13,17–19,24] water quality data were measured daily (or even at time of exposure[3,9])

Table 1 List of selected studies

First author	Year	Country	Study design	Water	Comments
Fleisher[3]	1996	UK	randomized controlled trial	marine	d
Haile[4]	1996	US	prospective cohort	marine	
van Dijk[5]	1996	UK	prospective cohort	marine	c
Bandaranayake[6]	1995	New Zealand	prospective cohort	marine	d
Kueh[7]	1995	Hong Kong	prospective cohort	marine	b
Medical Research Council[8]	1995	South Africa	prospective cohort	marine	a, c
Kay[9]	1994	UK	randomized controlled trial	marine	d
Pike[10]	1994	UK	prospective cohort/**	marine	a, b, c
Corbett[11]	1993	Australia	prospective cohort	marine	a, d
Fewtrell[12] *	1992	UK	prospective cohort	fresh	d
UNEP/WHO no 46[13]	1991	Israel	prospective cohort	marine	b, d
UNEP/WHO no 53[14]	1991	Spain	prospective cohort	marine	a, b, d
Cheung[15]	1989	Hong Kong	prospective cohort	marine	a, b
Ferley[16]	1989	France	retrospective cohort	fresh	a, b, c
Lightfoot[17]	1989	Canada	prospective cohort	fresh	
Fattal, UNEP/WHO no 20[18]	1987	Israel	prospective cohort	marine	b, d
Seyfried[19]	1985	Canada	prospective cohort	fresh	
Dufour[20]	1984	US	prospective cohort	fresh	a, b
Cabelli[21]	1983	Egypt	prospective cohort	marine	a, b, c
Cabelli[22]	1982	US	prospective cohort	fresh & marine	a, b
Mujeriego[23]	1982	Spain	retrospective cohort**	marine	b, a
Stevenson, 3-day study[24]	1953	US	prospective cohort	fresh	b, c, d

a: Only use of seasonal mean for analysis of association with outcome reported.

b: Control for less than three counfounders reported, or no reporting at all

c: Exposure not defined as head immersion/head splashing/water ingestion

d: <1700 bathers and 1700 non-bathers participating in the study.

* Exposure is white-water canoeing; similar to swimming, water intake is likely, while turn-over or through ingestion or inhalation of droplets.

** Cross-sectional study.

Remark: Two studies analyse the same data sets[5,10] but come to different conclusions.

and analysed according to the individual exposure day. In most of the other studies, only the seasonal water quality means of beaches were analysed for association with outcomes.

Twelve studies reported controlling for less than three non-water-related risk factors,[7,10,13–16,18,20–24] four studies for three to four of such potential confounding factors[6,11,12,19] and six studies reported controlling for seven or more of them.[3–5,8,9,17] Confounding factors included food and drink intake, age, sex, history of certain diseases, drug use, personal contact, additional bathing, sun, socioeconomic factors etc.

Study results

In 19 of the 22 selected studies, the rate of certain symptoms or symptom groups is significantly related to the count of faecal indicator bacteria or bacterial pathogen.[3,4,6–10,12–16,18–24] In one study[23] mycosis and eye and ear infections are inversely related to the count of faecal indicator bacteria. The author of this study states that this paradoxical finding could be due to the poor method of the water quality assessment, based exclusively on faecal coliforms, to evaluate the microbiological quality of coastal waters under certain conditions. In three studies,[5,11,17] no significant relationships were found with faecal indicators.

Several studies reported that symptom rates were more frequent in the lower age groups.[10,13,18,21]

Most associations were found between gastro-intestinal symptoms (including 'highly credible' or 'objective' gastro-intestinal symptoms) and indicators such as enterococci, faecal streptococci, thermotolerant coliforms and *E. coli*. Relatively few studies reported associations for other symptoms.

For evaluating the risk of contact with water itself, relative risks (RR) of exposure to relatively clean water were compared to non-swimmers. For gastro-intestinal symptoms, these RR all lie between 1.0 and 2.5,[9,10,12,16,20,22] with only one value being significantly different from 1.0.[22] For other symptoms, few data are available.

Relative risks of swimming in relatively polluted water versus swimming in clean water are compiled in Figures 1 and 2 and Tables 2 and 3 for numerical values. All RR range between 0.4 and 3.

The regression relationships that were available in the form of odds of illness or case rate versus bacterial count are compiled in Figure 3 for freshwater and in Figure 4 for marine water. These figures show that many studies suggest continuously increasing risk models with thresholds for various indicator organisms and health outcomes. Most of the suggested thresholds are low compared to water qualities often encountered in coastal waters of recreational use.[9,16,19,20,22,23] They range from only a few indicator counts/100 ml to about 30 counts/100 ml, and were higher for Egypt and Hong Kong (around 100–200 indicator counts/100 ml). These two studies also describe lower case rates for similar bacterial counts.

The indicator organisms which correlate best with health outcome were enterococci/faecal streptococci for both marine and freshwater, and *E. coli* for freshwater. Other indicators showing correlation are faecal coliforms and staphylococci. The latter are assumed to be correlated to bather density[15,18] and are significantly associated with certain symptoms, i.e. those affecting ear and skin and respiratory and enteric diseases.[15,18,19] The variation in staphylococci density could not be explained by sources of contamination other than cross-infection among bathers,[39] although further investigations would be necessary to confirm this hypothesis. Only one study finds significant correlations between gastro-intestinal symptoms and specific pathogenic bacteria.[7]

Figure 4 shows that Kay[9] reports a stronger relationship between exposure and gastroenteric symptoms than other studies. As this is the only randomized controlled trial on gastroenteric

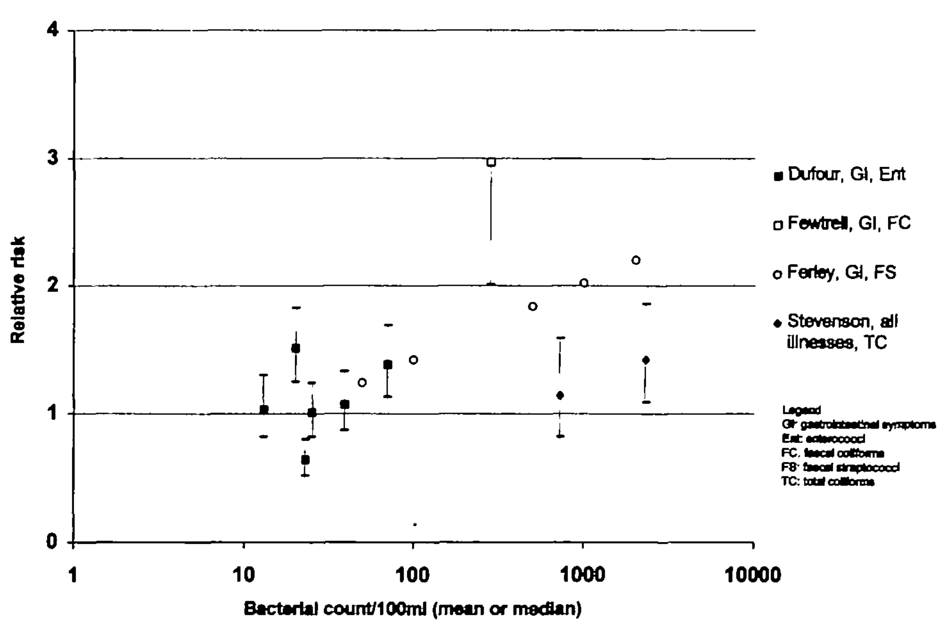

Figure 1 Relative risk for swimmers in relatively polluted freshwater against swimmers in unpolluted water

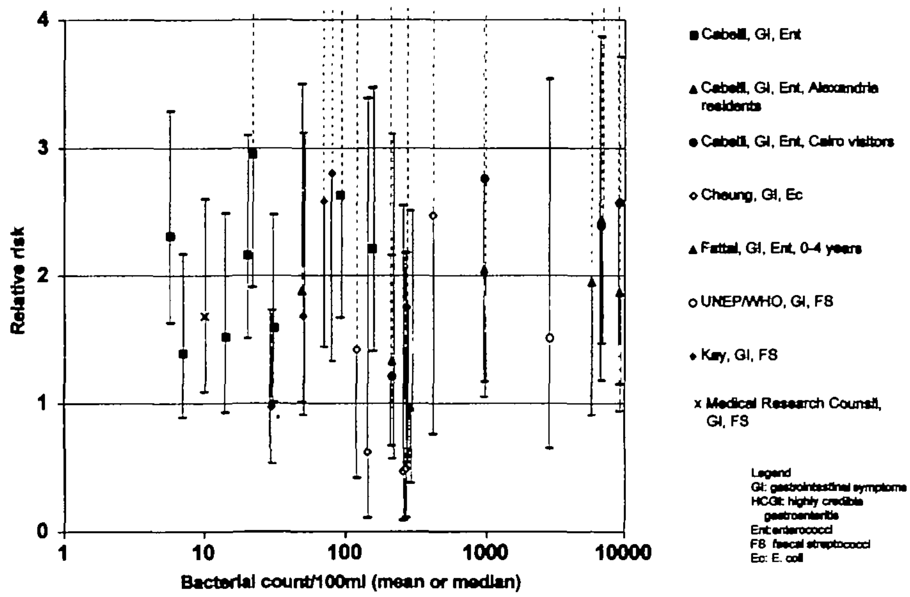

Figure 2 Relative risk for swimmers in relatively polluted marine water against swimmers in unpolluted marine water

Table 2 Freshwater—Relative Risk (RR), swimming versus swimming in differing water quality

Author (year)	Health outcome[a]	Indicator	Mean indicator count (per 100 ml)	RR (95%CI)	Incidence rate IR (*1000)	Exposure
Dufour	GI	enterococci	13 vs. 5	1.03 (0.82–1.30)	56 vs. 55	head
(1984)			20 vs. 5	1.51 (1.25–1.83)**	58 vs. 55	immersion
			25 vs. 5	1.01 (0.82–1.24)	55 vs. 55	
			71 vs. 5	1.38 (1.13–1.69)**	75 vs. 55	
			20 vs. 7	0.67 (0.53–0.84)**	38 vs. 57	
			23 vs. 7	1.64 (0.52–1.80)**	37 vs. 57	
			39 vs. 7	1.07 (0.87–1.33)	61 vs. 57	
Fewtrell	Flu	faecal	285 vs. 22	1.76 (1.31–2.37)**	445 vs. 252	white
(1992)	R	coliforms		1.51 (1.06–2.14)*	322 vs. 214	water
	Ear/Eye			3.53 (1.13–11.03)*	68 vs. 19	canoeing
	GI			2.97 (2.01–4.37)**	418 vs. 141	
	S			2.02 (1.05–3.86)*	137 vs. 68	
	All			1.59 (1.31–1.93)**	671 vs. 422	
Ferley	objective	faecal	50 vs. 20	1.24 (?)	12 vs. 10	bathing
(1989)	AGID	streptococci	100 vs. 20	1.42 (?)	14 vs. 10	
			500 vs. 20	1.84 (?)	18 vs. 10	
			1000 vs. 20	2.02 (?)	20 vs. 10	
			2000 vs. 20	2.20 (?)	22 vs. 10	
Stevenson	all	total	2300 vs. 37	1.42 (1.09–1.86)*	122 vs. 86	swimming
(3-day study)		coliforms	730 vs. 37	1.14 (0.82–1.59)	99 vs. 86	
(1953)						

[a] Ear/Eye = ear or eye infections; S = skin complaints; GI = gastro-intestinal symptoms; R = respiratory illness, AGID = acute gastro-intestinal disease.

*$P < 0.05$; ** $P < 0.01$.

Not all non-significant results are listed.

(?): CI not stated.

Table 3 Sea water—Relative Risk (RR), swimming versus swimming in water of differing quality

Author (year)	Health outcome[a]	Indicator	Mean indicator count (per 100 ml)	RR (95%CI)	Incidence rate IR (*1000)	Exposure
Bandarana-yake	R	enterococci	(1.5–4) vs. (0–1.5)	1.55 (0.66–3.63)	37 vs. 24	head
(1995)			(4–13) vs. (0–1.5)	1.76 (0.76–4.07)	42 vs. 24	immersion
			(13–232) vs. (0–1.5)	3.02 (1.31–6.93)**	71 vs. 24	
	HCGI		(13–232) vs. (0–1.5)	0.84 (0.27–2.63)	22 vs. 26	
Cabelli	GI	enterococci	154 vs. 3.5	2.21 (1.41–3.47)**	60 vs. 27	head
(1982)			91 vs. 3.5	2.63 (1.67–4.12)**	72 vs. 27	immersion
			31 vs. 3.5	1.59 (1.01–2.48)*	43 vs. 27	
			22 vs. 3.5	2.95 (1.91–4.56)**	81 vs. 27	
			20 vs. 3.5	2.16 (1.51–3.10)**	59 vs. 27	
			14 vs. 3.5	1.52 (0.93–2.49)	42 vs. 27	
			7 vs. 3.5	1.39 (0.89–2.17)	38 vs. 27	
			5.7 vs. 3.5	2.31 (1.63–3.29)**	63 vs. 27	
Cabelli	vomiting,	enterococci	residents			head
Egypt	diarrhoea		5760 vs. 103	1.95 (0.91–4.16)	31 vs. 16	immersion
(1983)			286 vs. 103	0.97 (0.38–2.51)	16 vs. 16	
			6780 vs. 73	2.44 (1.18–5.05)*	30 vs. 12	
			211 vs. 73	1.33 (0.57–3.11)	16 vs. 12	
			9160 vs. 214	1.87 (0.94–3.71)	19 vs. 10	
			954 vs. 214	2.05 (1.05–4.04)*	21 vs. 10	
			visitors			
			6780 vs. 73	2.39 (1.47–3.87)**	51 vs. 22	
			211 vs. 73	1.21 (0.67–2.16)	26 vs. 22	
			9160 vs. 214	2.57 (1.15–5.70)*	45 vs. 18	
			954 vs. 214	2.76 (1.17–6.51)*	48 vs. 18	
Cheung	HCGI	*E. coli*	119 vs. 69	1.42 (0.42–5.27)	3.1 vs. 2.1	head
(1989)			142 vs. 69	0.62 (0.11–3.39)	1.3 vs. 2.1	immersion
			254 vs. 69	0.47 (0.09–2.55)	1.0 vs. 2.1	
			266 vs. 69	0.49 (0.11–2.18)	1.1 vs. 2.1	
			269 vs. 69	1.75 (0.54–5.69)	6.5 vs. 2.1	
			414 vs. 69	2.47 (0.76–8.01)	7.4 vs. 2.1	
Fattal (1983)	GI	enterococci				head
and UNEP/WHO	age 0–4		49 (25–410) vs. 7 (0–14)	1.88 (1.01–3.50)*	209 vs. 111	immersion
MAP No. 20	all ages		49 (25–410) vs. 7 (0–14)	1.50 (1.01–2.23)*	104 vs. 69	+ splashing
(1987)	HCGI					+ swallow
	age 0–4		49 (25–410) vs. 7 (0–14)	2.07 (1.17–3.65)**	221 vs. 107	
	all ages		49 (25–410) vs. 7 (0–14)	1.36 (0.95–1.94)	104 vs. 76	
	other symptoms			NS		
Haile	S	faecal	642 vs. 5	2.02 (1.07–3.81)*	14 vs. 6	face
(1996)		coliforms	130 vs. 5	0.83 (0.39–1.76)	6 vs. 6	immersion
			51 vs. 5	1.94 (1.04–3.63)*	14 vs. 6	
Kay	GI	faecal	80+ vs. 0–19	2.80 (1.33–5.89)**	304 vs. 109	head
(1994)		streptococci	70(60–79) vs. 0–19	2.58 (1.44–4.64)**	281 vs. 109	immersion
			50(40–59) vs. 0–19	1.68 (0.91–3.12)	183 vs. 109	
			30(20–39) vs. 0–19	0.97 (0.53–1.73)	106 vs. 109	
Medical Research	GI	faecal	10.4(0–163) vs. 0.8(0–28)	1.68* (1.09–2.60)	61 vs. 36	entering
Council & CSIR		streptococci				water up
(1995)		faecal	21.9(0–436) vs. 3.8(0–324)			to or beyond
		coliforms				waist
UNEP/WHO	GI	enterococci	40(31–51) vs. 9(2–30)	1.95 (1.08–3.52)*	131 vs. 65	head immersion
MAP No. 46	R		40(31–51) vs. 9(2–30)	2.55 (1.27–5.05)**	124 vs. 47	+ splashing
(1991)						+ swallow
UNEP/WHO	enteric	faecal	2835 (130–11500) vs.	1.51 (0.65–3.54)	21 vs. 14	head immersion
MAP No. 53	dermatitis	streptococci	407 (40–1800)	2.02 (1.25–3.27)*	78 vs. 38	+ splashing
(1991)						+ swallow

[a] S = skin complaints; GI = gastro-intestinal symptoms; HCGI = highly credible gastro-enteritis; R = respiratory illness.

* $P < 0.05$; ** $P < 0.01$.

Not all non-significant results are listed.

NS: not significant

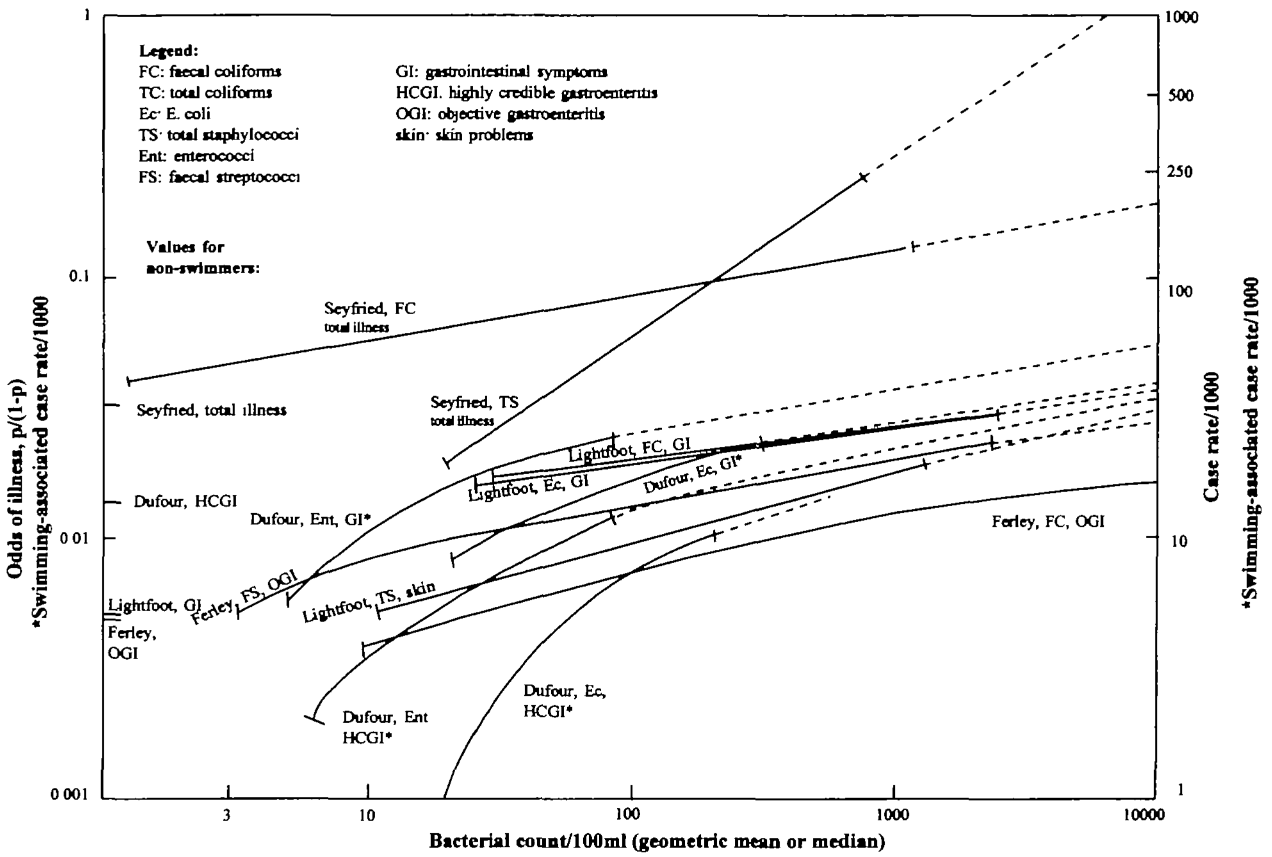

Figure 3 Predicted risk of illness in swimmers against bacterial count in freshwater; adapted and updated from Pike[46]

symptoms available, better assessment of individual exposure (water quality and degree of water contact assessment) may have reduced misclassification error. The same also applies to Fleisher's randomized controlled trial[3] investigating non-enteric illnesses. Comparison with other studies was not possible since this is the first study to investigate non-enteric illnesses according to the International Classification of Diseases (ICD-10), and due to the lack of other reported relationships.

The studies do not yield any findings on the relationship of severity of symptoms to differences in water quality.

Discussion

Some factors which may affect the validity of these studies are listed below. Table 4 recapitulates the main types of bias.

The *use of indicator microorganisms* for assessing water quality of exposure is one of the major sources of bias in such studies. Temporal and spatial indicator variation is substantial, and difficult to relate to individual bathers,[40] unless the study design is experimental.[3,9] Use of seasonal means for water quality rather than daily measurements further increases the inaccuracy. Also, the limited precision of methods for counting indicator organisms added substantial measurement error.[41] Furthermore, the indicator organisms used do not relate well to viruses, which may represent an important part of the aetiological agents. These factors lead to non-differential misclassification bias, and underestimation of the health effect of water quality.

Certain studies do not take into account the potential infection pathway for defining *exposure*, e.g. mainly head immersion or the ingestion of water[5,8,10,16,21,24] for gastro-intestinal symptoms. This, together with difficulties in exposure recall and reporting in observational studies, would also lead to non-differential misclassification.

The following factors will probably introduce minor bias:

Most observational studies relied on *self-reporting of symptoms*. Validation of symptoms by medical examination[3,9] would have reduced potential bias.

The *response rate* was more than 70% in all, and more than 80% in most studies. Differential reporting, e.g. higher response among participants experiencing symptoms, would probably not have major consequences.

The *recruitment method*, which consists of approaching people on the beach in almost all studies.

According to power calculations[42] the *study population size* should reach a minimum of 1700 swimmers and 1700 non-swimmers under the hypothesis of a 5% background illness rate and an excess rate of 50% for a significant result (90% power). Not all studies reached this number of participants,[3,6,9,11–14,18,24] however, excess rates were sometimes reported to be higher and so some studies could still yield significant results.

Since several of these causes may occur in one and the same study, the errors introduced are multiplied and can be very important, but would probably lead to underestimation of the health effect of water quality. Non-differential misclassification bias is the most important type of bias in the reviewed studies

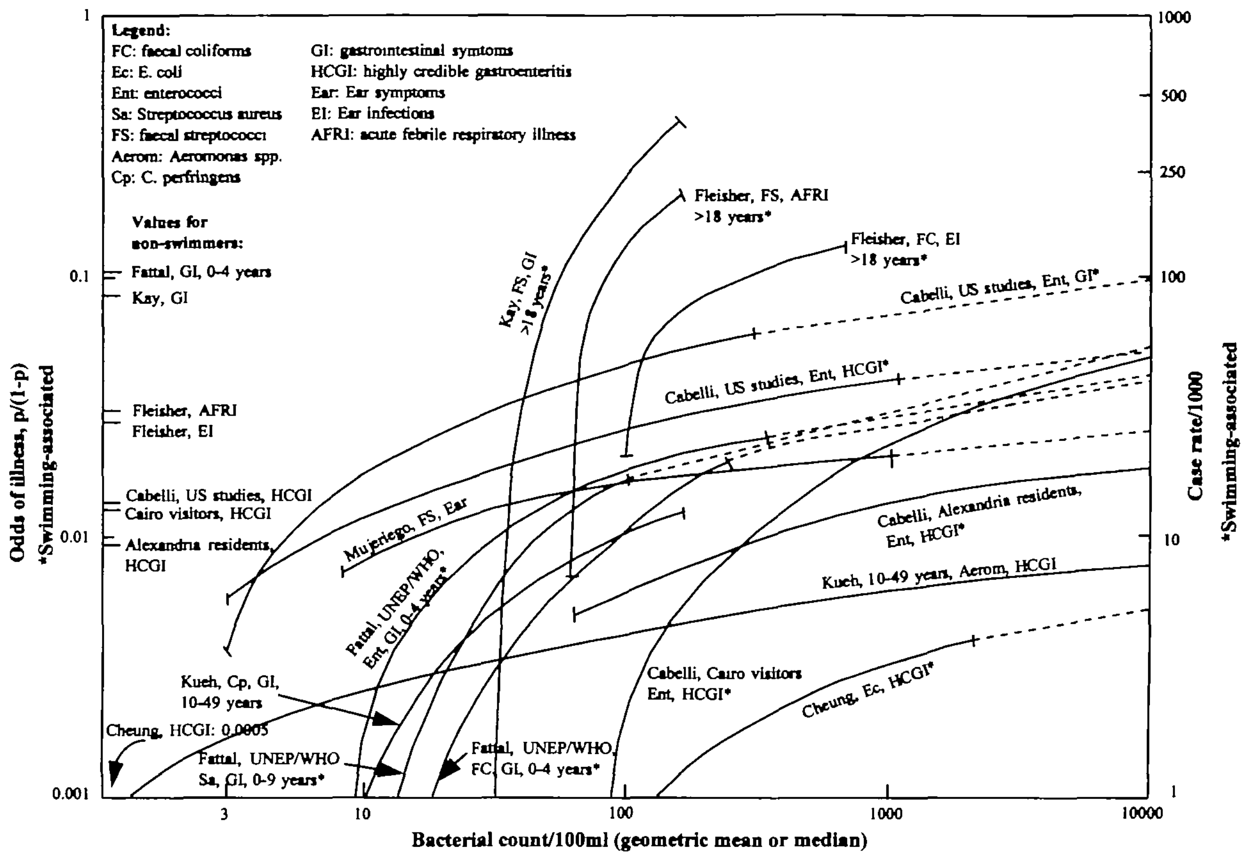

Figure 4 Predicted risks of illness in swimmers against bacterial count in marine water; adapted and updated from Pike[46]

Table 4 Main causes and consequences of bias in epidemiological studies of recreational water

Causes	Consequences
Use of indicators for assessing water quality	Probable underestimation of effect[a]
Selection of unrepresentative study population	Underestimation of effect if study population (e.g. adults) is more immune than population of interest
Exposure assessment	Usually underestimation of effect
Illness reporting	Under- or overestimation of effect
Non-control for confounders	Under- or overestimation of effect

[a] May be overestimation of the effect in case of sewage chlorination (e.g. Cabelli[22]), because the die-off of indicator organisms may be greater than that of certain pathogens.

and it should be smaller in the randomized controlled studies[3,9] than in the observational studies. This fact probably explains the higher risk estimates for gastroenteric symptoms and the stronger relationship with indicator counts, compared to the findings of the other studies.

Special attention should be given to the low threshold values reported. Misclassification of exposure may produce artificially low thresholds for increased risk. The one randomized controlled trial reviewed here analysing gastro-intestinal symptoms,[6] which should yield the most accurate relationship, suggests a threshold of 33 faecal streptococci/100 ml for increased risk of gastroenteritis, which is higher than in other studies. In addition to misclassification bias in observational studies, the difference in thresholds could be due to a study population limited to adults in the randomized controlled trial; their immunity status for diarrhoeal diseases being probably higher than for the average population.[43] Furthermore, study populations from Hong Kong[15] and Egypt,[21] show higher thresholds (and case rates). Also, within the Egyptian study, the visiting population (from another inland town) shows higher attack rates for gastroenteric symptoms than the local population. These results could not be explained by bias only and suggest the influence of immunity status on susceptibility to water quality, or a lower pathogen-to-indicator ratio in the natural waters. The thresholds may also be influenced by the sample size, i.e. they may decrease when the sample size increases. However, the Hong Kong and Egypt studies are among those with the largest sample size among the reviewed studies, whereas the sample size of the randomized controlled trial studying gastroenteric symptoms is relatively small.

Table 5 Criteria for causation in environmental studies (according to Bradford Hill). Application to bathing water quality and gastro-intestinal symptoms

Criterion	Fulfilment
1. Strength of association	Yes, significant associations have been found; the relative risks ratios are usually between 1 and 3
2. Consistency	Yes, the association has been observed in several countries and by various authors
3. Specificity of association	No, particular type of exposure is not linked with a particular infection or disease
4. Temporality	Yes, most studies permit to show that exposure precedes the disease rather than following it
5. Biological gradient	Yes, most of the selected studies show significant dose-response relationships
6. Plausibility	Yes: the results are in line with findings on ingestions of infective doses of pathogens
7. Coherence	Yes, the cause-and-effect interpretation of the data do not conflict with other knowledge on the disease
8. Experiment	No: preventive actions have not yet been described in the studies
9. Analogy	Yes: similar to ingestion of recreational water, gastro-intestinal symptoms are known to be caused by faecally polluted drinking-water

These studies have reported gastro-intestinal symptoms as the most common health problem related to the count of indicator bacteria in recreational waters. Respiratory, eye, ear/nose/throat and skin and mucosal symptoms in swimmers have also been investigated, and in a few studies, similar relationships were found. Relatively little epidemiological data on more serious health outcomes (e.g. hepatitis, leptospirosis, typhoid fever) are available.

The criteria for evidence in environmental disease causation, proposed by Bradford Hill,[44] and their fulfilment for the associations studied here, are described in Table 5.

In our review of 22 studies, seven of Hill's criteria are fulfilled. The criterion on the specificity of the association is not applicable because aetiologic agents are suspected to be numerous and relatively outcome unspecific. Results of experiments on the impact of preventive actions on health outcome frequency have not yet been reported.

Conclusions

The review of 22 selected studies suggests that there is a causal relationship between the gastro-intestinal symptoms and recreational water quality, measured by indicator-bacteria concentration, because they report a strong and consistent association with temporality and dose-response relationships, as well as biological plausibility and analogy to clinical cases in drinking water pollution.

In 19 out of 22 studies selected in this review, the rate of certain symptoms or symptom groups is significantly related to the count of faecal indicator bacteria in recreational water. Gastro-intestinal symptoms are the most frequent health outcome for which significant dose-related associations were reported. Symptom rates were usually higher in the lower age groups.

Several indicators were used for describing water quality in the reviewed studies. Most probably, the indicators showing correlation with health outcome varied according to faecal contamination of the water or contamination by other bathers. Consequently, despite different indicators, the trend in reported associations is similar.

For marine and freshwater, this review suggests low threshold values for increased risk compared to the water qualities frequently encountered in coastal recreational waters and suggests the existence of dose-response relationships between the bacterial count and symptoms. The results of the randomized controlled trials[3,9] are probably the most accurate, as exposure, water quality and illness are much more accurately assessed than in observational studies. These results are however primarily indicative for adult populations in temperate climates. Studies which report higher thresholds and case rate values (for adult populations or populations of countries with higher endemicities) may suggest increased immunity, which is a plausible hypothesis but requires further studies to confirm.

The WHO expert group for recreational waters agreed that the degree of convergence among principal study outcomes and findings provided a sufficiently solid basis from which to derive guideline values.[45]

Acknowledgements

I would like to thank Dr Richard Helmer and Dr Jamie Bartram, both at WHO, for their support work, and the WHO Expert Group on Health Impacts of Recreational Water and Bathing Beach Quality for its thoughtful discussions.

References

[1] WHO/UNEP. *Microbiological Quality of Coastal Recreational Water*. MED POL Phase II, Report on a joint WHO/UNEP meeting, 9–12 June 1993, Athens, Greece. WHO Regional Office for Europe, 1994.

[2] Feachem R, Garelick H, Slade J. Enteroviruses in the environment. *World Health Forum* 1982;**3**:170–80.

[3] Fleisher JM, Kay D, Salmon RL, Jones F, Wyer MD, Godfree AF. Marine waters contaminated with domestic sewage: nonenteric illnesses associated with bather exposure in the United Kingdom. *Am J Public Health* 1996;**86**:1228–34.

[4] Haile W *et al An Epidemiological Study of Possible Health Effects of Swimming in Santa Monica Bay*. Final report. California, 1996.

[5] van Dijk PAH, Lacey RF, Pike EB. *Health Effects of Sea Bathing—Further Analysis of Data from UK Beach Surveys*. Final report to the Department of the Environment. Report No. DoE 4126/3, Medmenham, UK, WRc plc, 1996.

[6] Bandaranayake DR, Turner SJ, McBride GB, Lewis GD, Till DG. *Health Effects of Bathing at Selected New Zealand Marine Beaches*. New Zealand, 1995.

[7] Kueh CSW, Tam T-Y, Lee T *et al*. Epidemiological study of swimming-associated illnesses relating to bathing-beach water quality. *Water Science Technology* 1995;**31(5–6)**:1–4.

[8] Medical Research Council & Council for Scientific and Industrial Research (CSIR). *Pathogenic Microorganisms/Epidemiological-Microbiological Study*. Final report 1991–1995; South Africa, 1995.

[9] Kay D, Fleisher JM, Salmon RL *et al*. Predicting likelihood of gastroenteritis from sea bathing; results from randomized exposure. *Lancet* 1994;**344**:905–09.

[10] Pike EB. *Health Effects of Sea Bbathing* (WMI 9021). Phase III: Final report to the Department of the Environment. Report No: DoE 3412/2, pub. Water Research Centre plc, Medmenham, UK, 1994, pp.I–38.

[11] Corbett SJ, Rubin GL, Curry GK, Kleinbaum DG. The health effects of swimming at Sydney beaches. The Sydney Beach Users Advisory Group. *Am J Public Health* 1993;**83**:1701–06.

[12] Fewtrell L, Godfree AF, Jones F, Kay D, Salmon RL, Wyer MD. Health effects of white-water canoeing. *Lancet* 1992;**339**:June 27.

[13] UNEP/WHO. *Epidemiological Studies Related to Environmental Quality Criteria for Bathing Waters, Shellfish-Growing Waters and Edible Marine Organisms (Activity D).* Final report on project on relationship between microbial quality of coastal seawater and rotavirus-induced gastroenteritis among bathers (1986–88). Athens, Greece, pub. United Nations Environment Programme; MAP Technical Report Series No. 46, 1991.

[14] UNEP/WHO. *Epidemiological Studies Related to Environmental Quality Criteria for Bathing Waters, Shellfish-Growing Waters and Edible Marine Organisms (Activity D).* Final report on epidemiological study on bathers from selected beaches in Malaga, Spain (1988–1989), Athens, Greece, pub. United Nations Environment Programme; MAP Technical Report Series No. 53, 1991.

Marino FJ, Morinigo MA, Martinez-Manzanares E, Borrego JJ. Microbiological-epidemiological study of selected marine beaches in Malaga (Spain). *Water Science Technology* 1995;**31(5–6)**:5–9.

(These two references document the same study)

[15] Cheung WHS, Chang KCK, Hung RPS. Variations in microbial indicator densities in beach water and health-related assessment of bathing water quality. *Epidemiol Infect* 1991;**106**:329–44.

[16] Ferley JP, Zmirou D, Balducci F *et al.* Epidemiological significance of microbiological pollution criteria for river recreational waters. *Int J Epidemiol* 1989;**18**:198–205.

[17] Lightfoot NE. *A Prospective Study of Swimming Related Illness at Six Freshwater Beaches in Southern Ontario.* 1989, Unpublished PhD Thesis. University of Toronto, Canada.

[18] UNEP/WHO. *Epidemiological Studies Related to Environmental Quality Criteria for Bathing Waters, Shellfish-Growing Waters and Edible Marine Organisms (Activity D).* Final report on project on relationship between microbial quality of coastal seawater and health effects. pub. United Nations Environment Programme; MAP Technical Report Series No. 20, Athens, Greece, 1988.

Fattal B, Peleg-Olevsky Agurshy T, Shuval HI. The association between sea-water pollution as measured by bacterial indicators and morbidity of bathers at Mediterranean beaches in Israel. *Chemosphere* 1987;**16**:565–70.

(These two references document the same study)

[19] Seyfried PL, Tobin RS, Brown NE, Ness PF. A prospective study of swimming related illness. I. Swimming associated health risk. *Am J Public Health* 1985;**75**:1068–70.

[20] Dufour AP. *Health Effects Criteria for Fresh Recreational Waters.* EPA 600/1-84-004, US Environmental Protection Agency, Cincinatti, Ohio 45268, 1984.

[21] Cabelli VJ. *Health Effects Criteria for Marine Recreational Waters.* Research Triangle Park, EPA, 1983, EPA-600/1–80–031.

[22] Cabelli VJ, Dufour AP, McCabe LJ, Levin MA. Swimming-associated gastroenteritis and water quality. *Am J Epidemiol* 1982;**115**:606–16.

[23] Mujeriego R, Bravo JM, Feliu MT. *Recreation in Coastal Waters, Public Health Implications.* VIèmes Journées Etud. Pollutions, Cannes, CIESM 1982, pp.585–94.

[24] Stevenson AH. Studies of bathing water quality and health. *Am J Public Health* 1953;**43**:529–38.

[25] Alexander LM, Heaven A, Tennant A, Morris R. Symptomatology of children in contact with sea water contaminated with sewage. *J Epidemiol Community Health* 1992;**46**:340–44.

[26] Brown JM, Campbell EA, Riskards AD, Wheeler D. Sewage pollution of bathing water. *Lancet* 1987;**ii**:1208–09.

[27] Calderon R, Mood EW. An epidemiological assessment of water quality and swimmers ear. *Arch Environ Health* 1982;**37**:300–05.

[28] Dewailly E, Poirier C, Meyer FM. Health hazards associated with windsurfing on polluted water. *Am J Public Health* 1986;**76**:690–91.

[29] El Sharkawi F, Hassan MNER. The relation between the state of pollution in Alexandria swimming beaches and the occurrence of typhoid among bathers. *Bull High Inst Public Health Alexandria* 1979;**IX**:337–51.

[30] Fewtrell L, Kay D, Salmon RL, Wyer MD, Newman G, Bowering G. The health effects of low-contact water activities in fresh and estuarine waters. *J Inst Water Environ Manag* 1994;**8**:97–101.

[31] Foulon G, Maurin J, Quoi NN, Martin-Bouyer G. Etude de la morbidité humaine en relation avec la pollution bactériologique des eaux de baignade en mer. *Revue Française des Sciences de l'Eau* 1983;**2**:127–43.

[32] Hoadley AW, Knight DE. External otitis among swimmers and non-swimmers. *Arch Environ Health* 1975;**30**:445–48.

[33] Kocasoy G. The relationship between coastal tourism, sea pollution and public health; a case study from Turkey. *The Environmentalist* 1989;**9**:245–51.

[34] McBride GB, Bandaranayake DR, Salmond CE *et al.* Faecal indicator density and illness risk to swimmers in coastal waters: a preliminary study for New Zealand. Proceedings of the Annual Conference of the New Zealand Water and Waste Association. Havelock North, 1–3 September 1993; New Zealand, pp. 43–49.

[35] New Jersey Department of Health. *A Study of the Relationship Between Illness and Ocean Beach Water Quality.* Interim Summary Report, New Jersey Department of Health, March 1989.

[36] Philipp R, Evans EJ, Hughes AO, Grisdale SK, Enticott RG, Jephcott AE. Health risks of snorkel swimming in untreated water. *Int J Epidemiol* 1985;**14**:624–27.

[37] Public Health Laboratory Service Sewage contamination of coastal bathing waters in England and Wales: a bacteriological and epidemiological study. *J Hyg* 1959;**43**:435–72.

[38] Seyfried PL, Cook RJ. Otitis externa infections related to *Pseudomonas aeruginosa* levels in five Ontario lakes. *Can J Public Health* 1984;**75**:83–91.

[39] Cheung WHS, Chang KCK, Hung RPS. Health Effects of beach water pollution in Hong Kong. *Epidemiol Infect* 1990;**105**:139–62.

[40] Fleisher JM, Jones F, Kay D, Stanwell-Smith R, Wyer M, Morano R. Water and non-water-related risk factors for gastroenteritis among bathers exposed to sewage-contaminated marine waters. *Int J Epidemiol* 1993;**22**:698–708.

[41] Fleisher JM. The effects of measurement error on previously reported mathematical relationship between indicator organism density and swimming-associated illness: a quantitative estimate of the resulting bias. *Int J Epidemiol* 1990;**19**:1100–06.

[42] Centers for Disease Control & Prevention (CDC), World Health Organisation. *Epi Info 6, Version 6.02,* 1994.

[43] Martines J, Phillips M, Feachem RGA. Diarrhoeal Diseases. In: Jamison DT *et al.* (eds). *Disease Control Priorities in Developing Countries* Oxford University Press/The World Bank, New York, 1993.

[44] Bradford Hill. The environment and disease: Association or causation? *Proceedings of the Royal Society of Medicine,* 1965,**58**:295–300.

[45] WHO Expert Consultation on Health Impacts of Recreational Water and Bathing Beach Quality, Bad Elster, Germany, 20–22 June 1996. EUR/ICP/EHPM 07 02 02, WHO EURO, Copenhagen, 1997.

[46] Pike EB, Balarajan R, Jones F et al. Health Effects of Sea Bathing (ET 9511) Phase II—studies at Ramsgate and Moreton 1990, 1991, DoE 2736-M(P), 1991.