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Do we all face the same risk when bathing in the estuary?

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ABSTRACT

With the development of coastal areas, microbial water quality is an emerging public health issue though few studies have focused on risks according to age. A survey was undertaken of faecal contamination in relation to recreational activities in the Peel Harvey estuarine system, Western Australia. Levels of exposure to contaminated water were estimated through social surveys. Follow-up was also conducted to estimate the incidence of disease associated with bathing in the estuary. Pathogen levels exceeded the guideline values recommended by the World Health Organisation (WHO) at most locations throughout the year. The social survey provided information about exposure of the population in age groups. Only 31% of the recreational users belonged to the healthy adult group upon which the WHO quantitative microbial risk assessment model is based. A correlation was established between microbial water quality and incidence of respiratory diseases for children as well as for adults. Exposure to recreational water increased the incidence of respiratory illnesses for the whole population almost by a factor 2. Behaviours which resulted in increased exposures were associated with increased incidence of illnesses were observed, particularly among children aged 11–15 yr, who exhibited the highest odd ratio (OR 4.23 [2.44–6.01], CI 95%, $p = 0.05$). There is a need for combining epidemiology studies with risk assessment processes and complementing them with social surveys for understanding the risk of recreational activities to public health.

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1. Introduction

With increased demands on recreational water resources, microbial contamination of surface waters is an emerging public health concern, particularly when farm, animal and sewage wastes are dumped into streams and lakes. Numerous studies suggest that bathing, windsurfing and other activities in such waters increase the risk of gastroenteritis, respiratory problems and ear, eye and skin ailments (Corbett et al., 1993; Fleischer et al., 1998; Kay et al., 1994; Prüss, 1998; Esfratiou, 2001). The studies inferred a causal relationship between gastrointestinal and/or respiratory symptoms and recreational water quality as measured by indicator-bacteria concentration.

Exposure during recreational usage of water environments is detailed by WHO (2003). Primary contact (direct contact) ranges from a direct contact where there is a negligible risk of swallowing water such as wading, to extensive direct contact with full body immersion, with an associated higher risk of swallowing water such as swimming. Children frequently appear in this latter group as they play longer in recreational waters, are more susceptible to infections than adults and are more likely to swallow (or even intentionally drink) recreational water.

Quantitative microbial risk assessment (QMRA) models relating to the health effects and dose–response curves—developed for drinking water and food—may be applied to the assessment of health risks from recreational waters (WHO,

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2001). However, as these models have been primarily developed for chemical agents (NHMRC, 2004), issues associated with immunity and transmission of disease are often ignored, particularly when many children are present. Some QMRA models have been applied to waterborne pathogens accounting for both immunity and person to person transmission (Eisenberg et al., 1996; Eisenberg et al., 1998; Soller et al., 2003). Risk in recreational waters was addressed using such a model in Soller et al. (2003). However, children should be taken into separate consideration in QMRA (Nwachuku and Gerba, 2004) as they may display attack rates higher than adults when swallowing water and submerging their head (Balbus et al., 2004). Age has also been investigated as the primary determining factor related to the type and severity of health outcomes from enterovirus exposures in recreational waters (Parkin et al., 2003); however, limited data on this subject are currently available in the peer review literature.

Children represent about 25% of the Australian population (ABS, 1999). Children, particularly from the age group 1–5 yr should therefore not be neglected in epidemiology studies focusing on waterborne diseases (Slack-Smith et al., 2004). Furthermore, Gerba (2000) estimated that children could be, through accidental faecal release, responsible for the shedding of 10^7 – 10^8 protozoan and 10^4 – 10^{13} enteric viruses per accident.

Most epidemiological studies focusing on recreational waters combined children and adult data or did not report age range of cases so that the proportion of illnesses among children, or simply the proportion of children could not be calculated. Only two quantitative studies provide epidemiological evidence that there is an increased risk of contracting enteroviral illnesses for children after swimming (D'Alessio et al., 1981; Kee et al., 1994) suggesting that the WHO guidelines mainly based on Kay et al. (1994) may underestimate risks to children. Parkin et al. (2003) recommended evaluation of risk by age subgroups as it may yield insights into risk factors and strategies for risk assessment modelling.

The Peel Harvey estuary provides a valuable example of the need to identify possible health hazards for children in term of recreational waters, as the estuary is shallow, connected to problematic catchments and has recreational areas frequently used by a growing population, including large groups of indigenous people. The study estimated the level of pathogens represented by faecal streptococci in a popular recreational area of the estuary over several months. Assessment of exposure in terms of duration and type of exposure included a survey of recreational users. An important component of the investigation was to assess the feasibility of quantitatively characterising the risk of susceptible sub-populations for contaminated water-related exposures.

2. Materials and methods

2.1. Description of the site and sample collection

The Peel-Harvey estuary is located 70 km south of Perth, the capital of Western Australia near the City of Mandurah. Water movement in the Peel-Harvey is caused by tidal currents, wind-driven circulation, density-induced circulation and

river flow. There are considerable data on the types and popularity of recreational activities in the Peel-Harvey (Lepesteur et al., 2003). The major recreational pursuits, both active and passive, include fishing, crabbing, prawning, boating, sailing, swimming, water skiing, picnicking and holidaying. Summer holiday periods result in a heavy burden on recreation areas and facilities, particularly those centred close to major boat ramps.

2.2. Sampling strategy

The monitoring strategy was designed to address weaknesses of previous epidemiological studies including the poor relation of bacteriological water quality to individual bathers (Esfratiou, 2001) as well as the lack of control on temporal and spatial variation (Fleischer et al., 1998). To eliminate these biases, the survey lasted 4 h in the afternoon—from 1 PM to 5 PM—on each occasion. The sampling location “Mandurah Bridge Beach” is located in the City of Mandurah, at the mouth of the estuary. The water recreational area was small (about 500 m²) suggesting that sampling would be close in space to the recreational users. Preliminary data showed that while indicator levels in the recreational area were higher in the afternoon than in the morning when the number of recreational users was lower, they did not significantly vary during the afternoon (data not shown). To reduce the short-term variability of the indicator (Boehm et al., 2002) duplicate samples were collected at 3 PM, on each day the survey was conducted as well as outside the bathing season. Two water samples were collected 30 cm below the surface inside the main swimming area, one of the duplicate a few metres from the “upstream side” of the enclosure (where the river water enters the swimming area), the second few metres from the “downstream side” of the enclosure (where the river water leaves the enclosure).

2.3. Water quality

Kay et al. (1994) showed faecal streptococci (FS) to be the only indicator organism that predicted gastroenteritis among bathers. Wade et al. (2003) and Prüss (1998) findings strongly support the point that enterococci is predictive of gastrointestinal illness risk. Fleischer et al. (1998) reported that exposure to FS could be predictive of acute febrile respiratory illnesses (AFRI). Preliminary investigations showed that FS rather than *E. coli* should be used as indicator of faecal contamination in the estuary as *E. coli* was only detected in the recreational area studied, but at very low levels (<10 cfu/ml). Duplicates samples were collected for the determination of faecal streptococci in waters and analysed according to the Australian Standard Method (AS 4276.9-1995). Weather conditions were monitored at the time of sample collection.

2.4. Exposure assessment

People were approached at the beach and a representative of each group/family was invited to participate in a first interview. A total of 119 groups/families corresponding to 340 individuals were enrolled in the study. The interviews focused on the frequency, length and days of visits, on the activities

undertaken and on the age of the users. Interviews were conducted face-to-face, with the surveyor completing the questionnaire (Frankfort-Nachmias and Nachmias, 1992).

One exposure to recreational waters was reported as any visit to the estuary exceeding 30 min (usually between 2 and 5 h) where the recreational user swam, paddled or/and played in the wet sand above the shoreline, these activities being considered here as primary contact. The authors arbitrarily choose to give the same importance to exposure to pathogens through wading, swimming and playing with wet sand. Recreationists' behaviours were observed and recorded (Babbie, 2002). The surveys were conducted on four occasions during the bathing season 2002–2003 (November 2002–March 2003) at “Mandurah Bridge Beach.” On each occasion, the survey was conducted for 4 h during the afternoon, with participation ranging from 75% to 90% of the recreational users present in the area.

2.5. Incidence of illness

During the first interview, people were asked about their current health status, including their use of medication, occurrence of respiratory or gastrointestinal illness, or any other ailment. A follow-up interview was conducted by telephone 2 weeks later. Information on who swam and who became ill within the family or group was gathered on that occasion. Gastrointestinal illness (GI) was recorded whenever an individual reported two or more occurrences of loose stools per 24 h or two or more incidences of vomiting, or diarrhoea with abdominal pain, vomiting or nausea or one episode of vomiting with abdominal pain or nausea or any of two of the symptoms together (Payment et al., 1997). The symptoms of GI did not include fever to include infections such as giardiasis. The case definition of respiratory illness (RI) was similar to that of McBride et al. (1998) who did not require fever to include common cold—as low-grade fever may not be noticed—but who neglected hay fever and asthma. We therefore focused on viral rhinosinusitis (common cold syndrome or non-specific upper respiratory tract infection), which is an acute illness typically characterised by rhinorrhea, sore throat, cough and low grade fever (Rosen-

stein et al., 1998). Rhinoviruses and coronaviruses are the main culprit as they together account for up to 60% of these infections (Anderson et al., 1993). Ear infection was recorded only when confirmed by medical examination.

Potential confounding factors such as food and drink intake, age, sex, history of disease, pregnancy, additional bathing, jellyfish sting, travel and period of exposure to sun were checked during the second interview.

We decided to adjust background illness rates reported in water recreational studies (Prüss, 1998) using age-dependent probability factors. The probability factors were derived from other studies that described different rate of illnesses in different age groups (Table 1). As an example, the probability factor for children under 5 yr when respiratory illnesses are considered would be 2.07 compared with adults (age 16–55) (Simmonds et al., 1999). The value derived for the population over 5 yr for respiratory illnesses would be similar to the background illness observed by McBride et al. (1998) for the same illnesses (6.8%) (Table 2).

Odd ratios (OR) with 95% confidence intervals (CI) were used to quantify the magnitude of effect of exposure to recreational waters for different age groups. Two-tailed Z-test was used to test the hypothesis that there was a significant difference between age groups. The power of the study ranged from 79.7% to 100% depending on the age groups considered.

3. Results

3.1. Water quality

Faecal contamination of the water was evident most of the year (Fig. 1). Increased concentrations during the bathing season in recreational areas reflected the impact of recreational users on water quality as confirmed by lower indicator levels detected upstream of the main swimming area. There was also an increase during the period of high rainfall and river discharge (June), in accordance with the significant increase of microbial concentration following rainfall observed by Crowther et al. (2001).

Table 1 – Probability factors and resulting background of illness incidence

Age group	Source	Probability factor	Background value
<i>Respiratory illnesses</i>			
[16–55]	Corbett et al., 1993	—	5.1
[0–5]	Simmonds et al., 1999	[0–5] vs. [16–55]: 2.07	10.6
[6–15]	Al-Yaman et al., 2002	[0–5] vs. [6–15]: 1.5	7.1
[0–67]	Simmonds et al., 1999	[16–55] vs. [0–67]: 0.62	8.2
<i>Gastrointestinal illnesses</i>			
[0–67]	Fattal et al., 1997	—	6.9
[0–5]		—	11.1
[6–55]		[6–55] vs. [0–67]: 0.73	5.0

All background value for respiratory illnesses are derived from the incidence of disease of 5.1% reported for unexposed adults on Sydney Beaches, Australia (Corbett et al., 1993).

Table 2 – Total (GI+RI) illness incidence observed for the whole population on the different occasions the survey was conducted

FS (CFU/100 ml)	Number individuals	Bathers (%)	Total illnesses (%) among bathers [CI, 95%, $p = 0.5$]
394 ± 22	130	68	52.9 [29.2–76.7]
642 ± 338	12	62	n.d.
246 ± 11	120	80	14.3 [6.5–22.1]
276 ± 16	90	77	16.7 [9.2–24.1]

The sample containing 642 FS/ml was taken during a rainy day in Summer.

Only one group of 12 individuals was present on the beach.

The data corresponding to that event were not included in the following calculations (n.d.—none detected).

The horizontal dashed line corresponds to the maximum of 35 faecal streptococci per 100 ml as recommended by the NHMRC guidelines (1990) and indicates faecal streptococci concentrations above the Australian guidelines for most of the year. On the right side of the graph, a table displays the risk of gastrointestinal and respiratory illnesses per exposure according to the FS concentrations as described by WHO (2003).

Fig. 1 – Temporal variations of faecal streptococci concentrations at Mandurah Town recreational area.

3.2. Exposure

Out of a total of 340 people enrolled in the study during the swimming season (January–February 2003), 76% identified swimming to be one of their recreational activities, followed by playing in wet sand (74%), fishing (51%), crabbing (48%), relaxing and having a picnic/barbecue (42%) and boating (27%). Most interviewees participated in several activities during their visit to the estuary and stayed 2–5 h (70% of respondents). Most (70% of respondents) were locals. Fig. 2 shows the number of exposures of primary contact users according to age. The age of participants ranged from few weeks to 67 yr old, with the age groups 16–25 yr and over 55 yr being poorly represented.

The average number of exposure was 17 per bathing season. Of the users 23% had only one or two exposures per swimming season; 49% had primary contact three to eight times per bathing season; 16% claimed 20–40 exposures within the same period, while 12% accumulated more than 40 exposures. Children (age 15 and under) made up 58% of the

Fig. 2 – Number of exposures per bathing season by age for primary contact (swimming/paddling and playing in the wet sand).

primary contact water users. Users aged 16–45, considered here as “healthy adults”, contributed only 31% of the primary contact users. Adults aged 46 and over were in minority (11%).

3.3. Illness incidence

The percentage of users becoming sick within 2 weeks after being surveyed is reported in Table 1 against FS concentration. Ear, nose and throat ailments made up most of the symptoms, with GI symptoms being much less common, as previously reported by Seyfried et al. (1985). Respiratory illnesses contributed to 58.3–100% of the incidence of disease.

Gastrointestinal illnesses were only recorded on one occasion, in children, with secondary infection observed in adults. Of cases of GI 100% were identified by the occurrence of vomiting and diarrhoea, giving confidence that cases detected were credible cases of GI (CGI). Hay fever was reported for non-swimmers but not recorded as illness. Respiratory illnesses reported by swimmers included asthma and hay fever (not recorded here), common cold and two cases of tonsillitis (adenovirus or Group A streptococci infection). Only one case of ear infection was reported.

Only 76% of the participants in the first interview were involved in the phone interview. The reasons included an unwillingness to give away phone details, a phone contact failure within the time frame as well as criteria which made them unacceptable for the purpose of the study (previous illness, time spent in the area under 2 h, etc.). We could, however, observe a relationship between excess of respiratory illnesses and exposure to pathogens expressed as levels of faecal streptococci (Fig. 3).

Fig. 4 provides density distribution of odd-ratios according to age groups. The distribution pattern, linked to recreational behaviour, illustrates the need for taking recreationists behaviour into account in risk assessment models. A jetty from which children jump into the water, finishing with a slide, used mainly by older children surrounded the recreational area investigated in this study. This type of activity, where water can be pushed into the nasal cavity, may have prompted the excess of illness in the age groups 11–25 yr. The highest OR was observed for the age range 11–15 yr (OR 4.23 [2.44–6.01] CI95%, $p = 0.05$). Several studies reported frequent

symptom rates in lower age groups (Cabelli et al., 1998; Fattal et al., 1997; Prüss, 1998). We noticed high RI and GI incidence rates in very young children (less than 5 yr old). Their activity, mainly playing with wet sand above the shoreline promoted sand and water ingestion, and may have resulted in an excess of GI and RI. The GI cases observed in the age group 26–35 yr corresponded mainly to secondary infection by contact between parents and children. The absence of illness in adults over 46 yr old may have resulted from the small sample size, but also from the swimming behaviour of older people, who were observed keeping their head above the water while swimming.

4. Discussion

The objectives of this study were to provide information for management of recreational activities in areas frequented by a very young recreational population (50% under 15 yr of age), overcrowded with bathers though having a low number of users for the purpose of epidemiological studies.

According to the WHO (2001) guidelines, recreational users swimming at Mandurah during the swimming season have an unacceptable risk of contracting a GI or RI illness (1.3% to more than 10% according to the time of the year) each time they swim (Fig. 1). However, QMRA provides estimates based on assumptions and extrapolations from existing data. The dose–response curves used in QMRA have been generated using healthy adult volunteers without existing diseases. In this study only 31% of the recreational water users (primary contact) belonged to that category. Of the population 50% was under 15 years of age, and was therefore more susceptible to water-related illnesses (Wade et al., 2003). A large majority of these children (>90%) were wading, swimming or playing with wet sand above the shoreline. The expected relative exposure to pathogens for wading or playing with wet sand above the shoreline was expected to be different (lower) from the exposure upon which the WHO guidelines were based.

Fig. 3 – Relationship between respiratory illnesses due to exposure to recreational water and levels of bacterial indicator.

Age group	Odds ratio (exposed/unexposed)	Behaviour increasing risk	Behaviour decreasing risk
[0-67]	1.92 [1.29-2.54]		
[16-55]	1.43 [0.12-2.99]	Jumping/energetic swimming (16-25 years)	Calm swimming with head above water (>45 years)
[0-5]	1.58 [0.51-2.64]	Playing with wet sand/water (ingestion)	Paddling below waist or knee/ankle depth level (<1 year)
[6-10]	1.13 [0.07-2.19]	Swimming	Paddling below waist
[11-15]	4.23 [2.44-6.01]	Jumping/energetic swimming	-

Fig. 4 – Distribution of odd ratios between swimmers and unexposed individuals for contracting respiratory illnesses per age group and observed recreational behaviour.

However, use of the beach by diapered-children that may increase the potential for water-borne disease transmission (Carpenter et al., 1999) and presence of gulls may have resulted in higher relative exposure for playing in the wet sand. Levels of FS indicator in sand showed that beach sand may be a reservoir for pathogens (data not shown).

Epidemiological studies, particularly observational studies, have been preferred to risk assessment, as they take into account the burden of disease associated with exposure to an infective agent as well as social data characteristic of the immune status of the population. The main problem with epidemiological studies is coping with the very large number of variables, which can affect the rates of illnesses. This study accounted for symptoms deriving from sources excluding the recreational water, such as food, alcohol and sunbathing.

Prüss (1998) suggested that, although prospective studies were suitable for investigating health risks associated with recreational waters, variation of composition in the different exposure groups and the loss of participants during follow-up may impact on the reliability of the data obtained. The recreational area at Mandurah town is used by large groups of extended families (up to 61 individuals in one single group). Significant loss of follow-up can result if one group cannot be contacted. The large groups and families may also have contributed to bias in the study by creating clusters of illnesses. However, the short time frame (2 weeks) between the two interviews, and the simultaneity of symptom appearance in most cases led us to conclude that clusters were not important in our study. Furthermore Prüss (1998) calculated that for significant results, 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%. Such sample size could not be achieved in the present study, as 100 people or less were present at any time during the interview periods. The sample size may explain the absence of relationship between GI and FS in particular.

One of the major constraints of this study was the presence of large groups. The failure to contact the representative for a large group for the second interview reduced the size of the sample. Problems with clusters of illnesses that may result in overestimation of the illness rate are discussed below.

Studies using non-swimming control groups, as well as studies focused on children found elevated relative risk (RR) (Wade et al., 2003). However, non-swimmers might not have swum because of health conditions, introducing bias to the study. There were few non-swimmers in this study, and some of them clearly indicated that a respiratory illness was preventing them from swimming.

The main issues of concern in the present study included the unreliability of self-reported information about the symptoms. However, the requirement for two or more symptoms of illness, and medical confirmation for ear infections decreased bias from this issue. Another issue was the impact of variables such as swimming duration, water activity, age, gender, health condition and local immunity on vulnerability to contaminated water (Machado and Mourato, 2002). The vast variation in resistance or immunity among the population makes it impossible to calculate accurately the effects of swimming in polluted waters. Miscalculation of exposure may produce an artificially low threshold for increased risk (Prüss, 1998), and a difference in threshold

could be due to a study population limited to adults (higher immune status resulting in higher threshold), or to a lower pathogen/indicator ratio. Here the threshold was quite high (251 FS per 100 ml for the whole population, 235 FS per 100 ml for children (<16 yr), and 260 per 100 ml for adults (16–55 yr), (see Fig. 3)), most likely due to a lower ratio between pathogen and indicator resulting from a repetitive stirring of the sediments (Youn-Joo et al., 2002).

However the attack illness rate was higher than that predicted by WHO for FS concentrations above 238 FS per 100 ml. The study of Kay et al. (1994) on which WHO predictions are based was conducted in northern European waters (2001). The dose–response relationship they established may not be applicable in Western Australia, where a threshold more representative of warmer waters may be more appropriate. Higher threshold for increased risk has also been, in some countries, linked to immunity due to endemicity (Prüss, 1998), or local immunity. Since most of the study participants (70%) were local residents, local immunity might have reduced the excess illness among bathers at low FS levels.

The main issue of this study was that the non-swimming population was so poorly represented that it could not be used for assessing the background incidence of illness in unexposed population. Furthermore, the low illness rates observed in people sick at the time of the first interview could merely indicate that people generally avoid the beach when sick and the OR of 1.6 between sick children and adults would therefore not be a reliable value for comparing background of illness. The choice of a reliable value representing background of illness is difficult as few relevant data are reported in the literature. This choice becomes even more difficult when children are involved. Background of illnesses and confounders have been mainly reported in relation to childcare attendance. Slack-Smith et al. (2004) reported rates of 0.49 per annum of AFRI in child care settings, corresponding to OR of 1.46. Fleming et al. (1987) observed 24% of upper respiratory infection (URI) and 6% of ear infection in children under 5 yr old during a period of 15 days, corresponding to ORs of 1.6 ($p = 0.02$) and 3.8 ($p = 0.05$), respectively, when assuming a background level of 15%. In Western Australia, more than half of children under 5 yr do not attend childcare (ABS, 1999). This, and the fact that the study was mainly conducted over summer holidays led us to assume that childcare attendance would not be an important confounder in that study, even if it may impact immune levels, therefore attack rates at relatively low FS concentrations.

The incidence of illness reported in recreational studies for an unexposed population is often lower than the incidence of illness reported in other studies, particularly when respiratory illnesses are considered, mainly because the incidence of respiratory illnesses is often lower during the summer months. Relying on incidence of illness derived from data collected in winter to estimate the odd ratios between incidence of illnesses in exposed versus unexposed populations would lead to underestimation of the relative risk associated with recreational water exposure. On the other hand, there is a peak period for gastrointestinal illnesses during spring and summer (Hargreaves et al., 1995).

The degree of difficulty increases when considering sub-populations corresponding to different age groups. Swim-

ming duration and water activity were also important variables as exposure through inhalation may increase with vigorous activity. Elevated relative risk of vigorous swimming and body surfing (compared to bathing) have been reported (Bradley and Hancock, 2003). Z-test using two-tailed test ($\alpha = 0.05$) showed that exposure to recreational water increased significantly the incidence of respiratory illnesses for the whole population by almost a factor two ($p = 0.0002$, $p < \text{two-tailed}$). When considering age group subpopulations, the increase was statistically significant only for the age group 11–15 yr. The lack of significance for other age groups could merely be due to the small sample size. The choice of an appropriate rate of background illnesses was also important as, in the present study, applying the same rate to all children sub-populations would have resulted in a statistically significant increase of respiratory illnesses in the age group 0–5 yr old.

We proposed that the water recreational activity behaviour associated with the 11–15 yr water recreational activity was responsible for the high incidence of respiratory illnesses. Other behaviours that could influence the incidence of disease are suggested in Fig. 4. This study suggested a relationship between incidence of disease and age group based on the recreational behaviour the different age groups exhibit. This relationship would be consistent with a true dose–response relation rather than the concentration–response relation upon which recreational criteria are based. In a QMRA paradigm, these concentration–response functions assume a constant exposure volume. The results of this study seem to indicate that such an assumption may not be valid for all ages. Because of the small size of the sample, significant relationship between RI incidence and age group—consequently dose–response relation—could only be established for the age group 11–15 yr. Further research into recreationist behaviour and its implication for risk assessment models is therefore needed.

5. Conclusions

- Existing quantitative risk assessment models could not be applied to this system, as only 31% of recreational users belonged to the category of users upon which the QMRA models are based. An epidemiological approach linked faecal streptococci levels to the burden of disease and excess illness rates, in particularly within the population of children, which contribute to more than 50% of the recreational population.
- Current limitations to the accurate development of public health risk models for recreational water use lie with the lack of integrated occurrence studies characterising not only factors such as pathogen and indicator ratio, but also socio-demographic factors and behaviour of the recreational population.
- This study also points out the difficulties in getting significant results when conducting epidemiology studies in recreational areas involving small number of people.
- This study integrating behavioural surveys of recreationists with water monitoring provided data amenable to determining/applying QMRA models and led to

recommendations to improve assessment of the exposure of susceptible subpopulations to pathogens by expressing it in terms of a true dose–response relation rather than concentration–response relation.

- Observational studies, focusing on the association between recreational behaviour and incidence of diseases, and in particular, looking at the amount of sand ingested versus amount of water ingested by toddlers could provide useful information about their real exposure in natural recreational water environments.

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